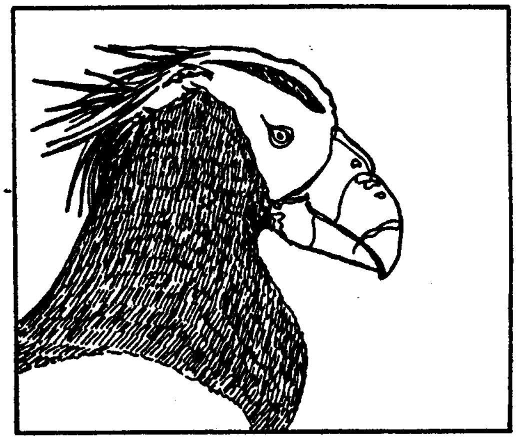
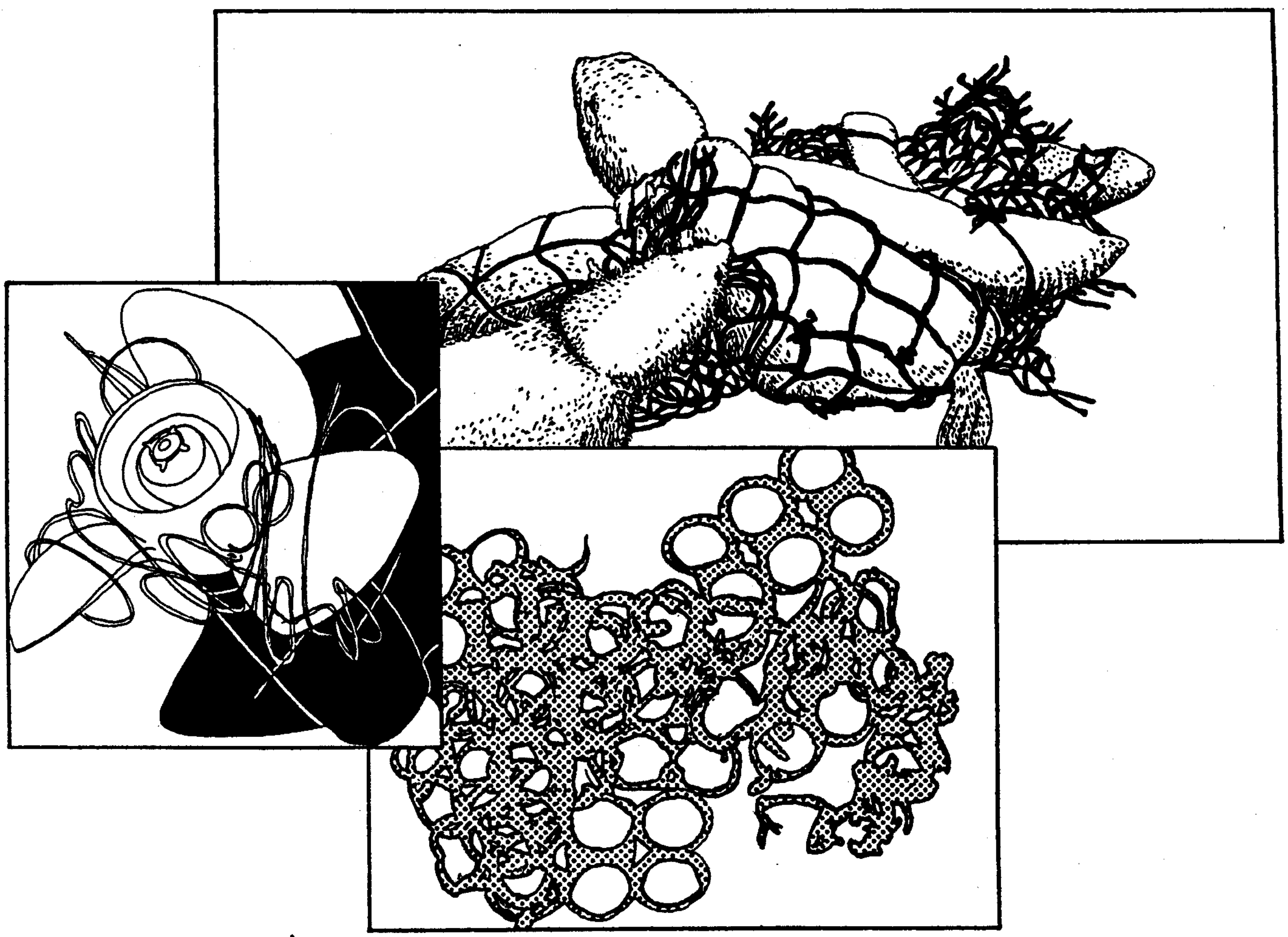
SESSION V



SOLUTIONS THROUGH TECHNOLOGY



THE PHILOSOPHY AND PRACTICE OF DEGRADABLE PLASTICS

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ABSTRACT

A major advantage of plastics in packaging is their resistance to attack of microorganisms. After discard, however, this characteristic creates major problems in their disposal, since unlike nature's litter, they do not return to the biological cycle. Strategies for retaining the advantages of plastics during use but of triggering biodegradation after discard are discussed. Photobiodegradable plastics which have been used successfully as agricultural mulching film for many years are seen to be the potential solution to the marine debris problem.

THE ENVIRONMENTAL IMPACT OF PLASTICS

The growth of consumer packaging has been one of the most visible phenomena of the twentieth century. On balance, it has been a beneficial development which has facilitated the distribution and storage of perishable goods to the advantage of the international community.

The modern packaging industry has its roots in the petrochemical industry, and the cheap commodity plastics, polyethylene, polypropylene, polystyrene, and polyvinyl chloride, are the major polymeric materials currently in use. They have a number of advantages in common, of which the following are the more important:

- They are cheap and easy to fabricate into common items of packaging.
- They are resistant to water and microorganisms and are, therefore, able to protect perishable goods from biological attack.

However, the very characteristics which make plastics so useful in packaging cause considerable problems in their ultimate disposal. Unlike cellulosic packaging materials (paper, cardboards, and the cellulose-based plastics), the oil-based plastics do not biodegrade back to the carbon

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

cycle when discarded in the environment. This is why they present one of the most visible litter problems of the twentieth century. The persistence of plastics litter in recreational areas, where it gave maximum offense, became evident in the late 1960's. The response of the plastics industry at that time was to say that it was unlikely that technical solutions to this problem could be found because the characteristics of biodegradable plastics were "the antithesis of the nature of packaging materials" (Staudinger 1970). The Society of Chemical Industry in 1970 expressed its alternative strategy as follows:

> ". . .the Society will seek to make common cause with all movements and organisations concerned with preventing environmental deriliction [sic] by littering" (Staudinger 1970).

This did not mean that they would encourage research into making plastics more biocompatible, but that they would encourage educational programs directed toward making the public more environmentally aware of the litter problem. This is still essentially the polymer industry's public stance today. The responsibility for plastics pollution is presented as that of the user, who must be educated into nonlittering habits (Claus 1987; O'Connell 1987; Society of the Plastics Industry 1988).

In the meantime, the problem continues to grow. There was a temporary respite in the mid-1970's, when it appeared that the oil crisis would lead to widespread recycling of plastics waste. This did not happen on any scale for technical and sociological reasons, and the problem became more severe even through the years of high polymer prices.

One of the earliest surveys of plastics pollution in the seas was carried out by the author in the early 1970's. Over a 3-year period, a fivefold increase in plastics litter was observed on a remote shoreline in northwest Scotland (Table 1) (Scott 1972a, 1975a). The conclusion drawn from this survey was that most of the plastic litter found on the seashore is seaborne and wind driven. The nature and location of the litter suggested that it came predominantly from shipping and not from local inhabitants or visitors. In this context, the good intentions of the educators were seen to be both misguided and misdirected. Commercial pressures to use the sea as a convenient "waste bin" have proved to be much more persuasive than homilies by The Tidy Britain Group, and even the threat of legislation has little effect due to the difficulty of policing this on the high seas.

This early evidence of sea littering has been confirmed by many subsequent studies (Dixon and Cooke 1977; Dixon 1978; Dixon and Dixon 1981; Fowler and Merrell 1986; Andrady 1987; Heneman 1988), and there is increasing evidence that plastics debris can kill birds and animals by ingestion and strangulation (Fowler and Merrell 1986; Andrady 1987; Heneman 1988).

Certain types of nonbiodegradable plastics waste have come in for most criticism over the years. The most visual and intrusive are the large polyethylene bags used for packaging agricultural and industrial products and domestic carrier bags, all of which float on the sea and accumulate on land. Even more aesthetically objectionable are the smaller items which

Table 1.--Accumulation of plastic litter at Strathaird Point, Isle of Skye, Scotland, in a 3-year period (number of packages per 50 yd).

Type of packaging (polymer)[a]	August 1971	August 1974
Detergent (LDPE)	7	5
Detergent (HDPE)	--	31
Bleach, sanitary fluid (HDPE)	15	49
Oil (HDPE)	4	18
Cosmetic (HDPE)	3	3
Carpet cleaner (HDPE)	--	5
Food (HIPS or ABS)	1	7
Table salt (HDPE)	--	10
Milk (HDPE)	--	16
Heavy gauge bags (LDPE)	2	6
Small transparent bags (LDPE)	--	29
Carrier bags (LDPE)	--	5
Heavy gauge sheets (LDPE)	6	15
Miscellaneous unidentified	3	14

[a]LDPE - low density polyethylene, HDPE - high density polyethylene, HIPS - high impact polystyrene, ABS - acrilonitrile-butadiene-styrene copolymer.

originate from sewage disposal and which, although probably harmless compared with other components of sewage, cause great offense on beaches and in other environmentally sensitive areas (Johnson 1987). Six-pack collars, used for carrying beer and soft drink cans, have been particularly indicted as a cause of entanglement for birds and small animals, and discarded ropes and fishing nets are equally a cause of suffering and sometimes death to wildlife. These are all examples of litter which does not biodegrade, and although the polymers do degrade slowly under the influence of sunlight and oxygen and the erosive influence of the weather, these natural processes are not fast enough to eliminate the dangerous effects of man-made polymers in the environment.

Fortunately, a good deal of work in academic laboratories, particularly in the United Kingdom and Canada, had led to an understanding of the chemistry involved in the oxidative degradation of polymers. Associated with this was a fundamental understanding of antioxidant and ultraviolet (UV) stabilizer mechanisms which suggested the possibility of designing polymers with controlled outdoor stability.

THE ENVIRONMENTAL STABILITY OF POLYMERS

Biodegradability of Polymers

As has been discussed above, the main reason that the man-made polymers have assumed a position of such importance in the packaging industry is because of their excellent water barrier properties. Since they are not readily penetrated by water, they act as an effective barrier, even in very thin films, to the attack of microorganisms. However, just because they are not accessible to microorganisms, they normally remain resistant to microbiological attack after discard in the environment.

All man-made polymers are not so hydrophobic as the carbon-chain polymers, however, and in general, the closer in structure polymers are to the natural polymers, the more biodegradable they become. Thus, the polyamides, which resemble the polypeptides in chemical structure, do absorb water and slowly biodegrade. In the case of polyurethane foams, biodegradation may take place quite rapidly because of the high internal surface area of the foam structure. Recently, man has been able to utilize nature's ability to synthesize and store within the biological cell certain types of polyester (Table 2) to produce a truly biodegradable polymer with physical and mechanical resemblances to the polyolefins (Lloyd 1987).

It is an unfortunate irony, however, that the nearer synthetic polymers approach the structure and properties of the natural polymers, the less useful they become as packaging materials because of the impairment of their barrier properties. Cellulose-based packaging has been largely abandoned over the years in favor of the hydrophobic polymers, and it is highly unlikely that the packaging industry would now be willing to return to less effective materials even if they could be produced at the same price as commodity plastics. It appears then that some other stratagem has to be sought to ensure that packaging materials are returned to the biological cycle when discarded in the outdoor environment.

Oxidative Degradation of Polymers

All organic polymers degrade due to the combined effects of oxygen, sunlight, and water by processes which do not, at least in the early stages, involve biological agencies (Scott 1965). They do so, however, at rates which differ by several orders of magnitude. Fluorinated polymers (e.g., Teflon) are in general the most resistant to environmental deterioration, and in the absence of light they can survive for many decades. Hydrocarbon polymers, and particularly the unsaturated rubbers, are much less resistant to oxidation, and even polyethylene, which on the basis of its structure should be chemically inert, does oxidize slowly unless protected against the effects of the environment. The small amounts of antioxidants which are added as processing stabilizers are normally sufficient to effectively stabilize polyethylene against the effects of oxidation in the absence of sunlight, but much more effective combinations of antioxidants and light stabilizers have to be used in order to give the polymer the durability required for use in outdoor applications (Scott 1979-88; Grassie and Scott 1985).

Oxidation of polymers leads to the formation of a variety of oxygen-containing functional groups as part of the polymer chain, of which the most important are hydroperoxides, carbonyl groups, alcohols, and carboxylic acids (Fig. 1) (Grassie and Scott 1985). These lead to the modification of the polymer surface, making it hydrophilic and allowing microorganisms to preferentially remove the oxygen functions. Figure 2

Table 2.--Commercially available degradable plastics.

Common description	Composition	Trade name	Manufacturer
		Biodegradable polymers	
Poly (3-hydroxy-butyrate-3-hydroxy valerate)	Biosynthetic copolymer of 3-hydroxybutyric and 3-hydroxy-valeric acids	Biopol	ICI (United Kingdom)
		Polymers containing a biodegradable filler[a]	
Starch-filled polyethylene (Griffin process)	Physical blend of LDPE and starch	Bioplast Ecostar	Coloroll (United Kingdom) St. Lawrence Starch (Canada)
		Photodegradable copolymers	
Ethylene-carbon monoxide copolymers		E/CO	DuPont (United States) Union Carbide (United States) Dow (United States)
Vinyl ketone copolymers (Guillet process)	Copolymers of ethylene, propylene, and styrene with a vinyl ketone	Ecolyte	EcoPlastics (Canada)
		Photosensitizing and photoactivating additives	
Iron salts	Probably ferric stearate	PolyGrade	Ampercet (United States)
Aromatic ketones	Probably benzophenone with metal stearates	Not commercial	Princeton Polymer Lab. (United States)
Antioxidant photoactivator (Scott-Gilead process)	Ferric thiolates (sometimes with other metal thiolates (in polyethylene)	Plastor	Plastopil (Israel) Polydress (Germany)
		Greenplast	Enichem Agricultura (Italy)
		Plastigone	Plastigone Technologies Inc. (United States)
		Ecoten[b]	Amerplast (Finland)
		Litterless	Plastigone Technologies Inc. (United States)
	(in polypropylene baler twine)	Cleanfield	American Brazilian Company (United States)

[a]LDPE = low density polyethylene. [b]Manufacture discontinued.

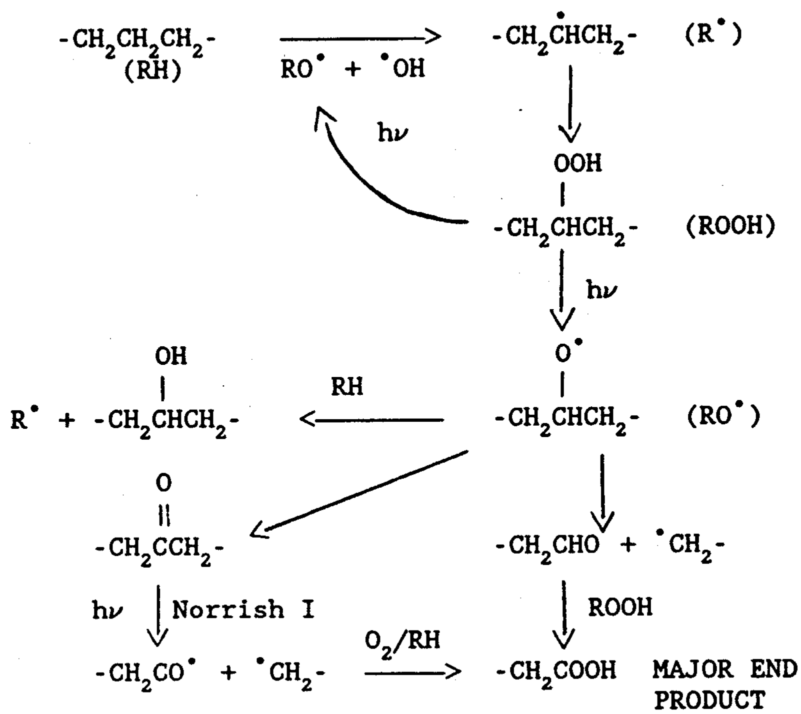


Figure 1.--Products formed in the photooxidation of polyethylene.

shows that polyethylene, stored under ambient conditions, develops a substantial concentration of carbonyl compounds (1,710-1,735 cm^{-1}), and that these can be selectively removed by microorganisms, leaving a chemically "purer" polymer behind (Grassie and Scott 1985).

Deliberate preoxidation of polyolefins leads to an enhanced rate of attack of thermophilic fungi at 40°-45°C due to the formation of readily assimilable dicarboxylic acids (Eggins et al. 1971). Some plasticizers also accelerate this process, probably in part by accelerating the autoxidation of the polymer (Eggins et al. 1971). Recently, the addition of oxidizable oils (e.g., soybean oil) to polyethylene has been used to accelerate the rate of thermal oxidation of starch-filled polyethylene in compost at elevated temperatures in order to make the starch available to microbiological attack (Griffin 1987; Maddovar and Chapman 1987). The rationale behind this approach to biodegradable polyethylene is not entirely clear, since the starch is encapsulated in biologically resistant polymer which does not oxidize at a significant rate at ambient temperatures. Moreover, the process cannot occur in landfill because no oxygen is present and the unoxidized polymer backbone cannot be assimilated by microorganisms (Potts 1982).

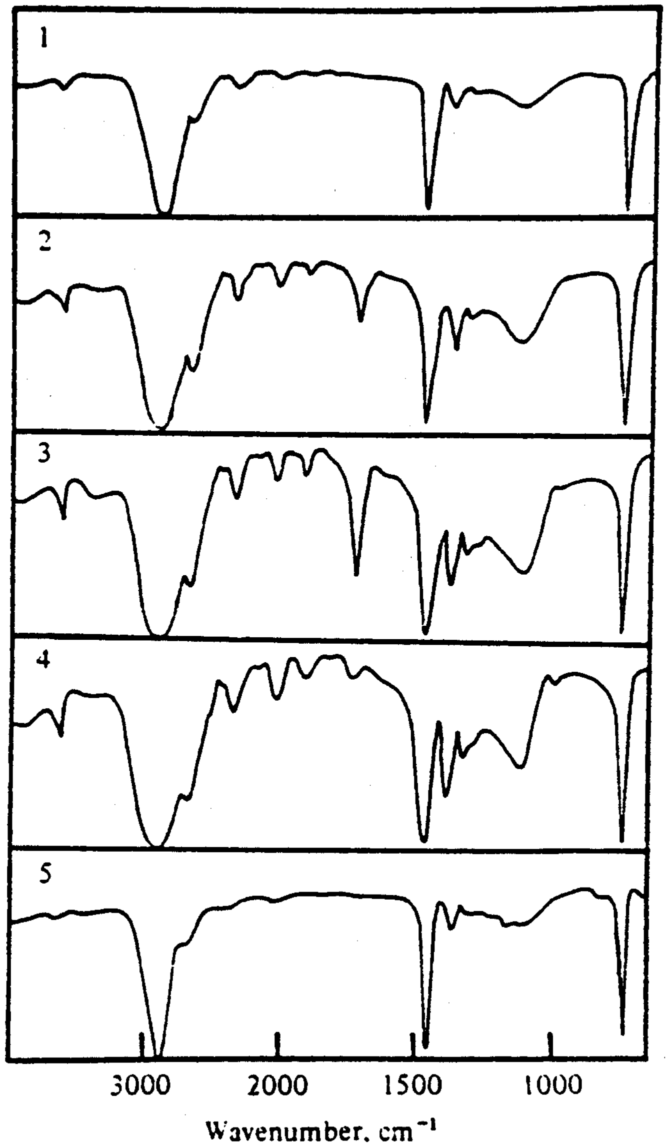


Figure 2.--Infrared spectra of high density polyethylene (HDPE) films with different histories: 1--with antioxidant after standing at ambient temperature for 1 year; 2--as 1 without antioxidant; 3--as 2 after standing for 3 years; 4--as 3 after treatment with an aerated medium inoculated with cultivated soil; 5--HDPE powder without antioxidant exposed to aerobic biodegradation for 2 years before molding to film with exclusion of air. (Grassie and Scott (1985) with permission, originally reproduced from a doctoral thesis by Dr. A. C. Albertsson with permission.)

Photooxidation of Polymers

Thermal oxidation of polymers is not a very controllable process. Although it can be catalyzed by cooxidation agents or transition metal ions, these are present in varying amounts of foodstuffs. However, autoxidation is readily inhibited by antioxidants, which are deliberately added to stabilize the polymer during manufacture (Grassie and Scott 1985). Furthermore, the addition of even a few percent of polymer-soluble coagents substantially alters the physical characteristics of the polyolefins (Scott 1988a, 1988b).

Photooxidation, by contrast, is a much more controllable process, since it is not appreciably affected by thermal antioxidants or contaminants. As early as 1971, it was suggested (Eggins et al. 1971) that controlled photooxidation was a potentially useful way of dealing with the problem of nonbiodegradable packaging litter. It offers the very considerable advantage over true biodegradation of the main polymer chain that, until photooxidation has occurred in the environment where the package has been discarded, its properties do not differ in any respect from conventional packaging made from the same polymer. The mechanism of photooxidation is essentially similar to that of thermal oxidation. The essential difference is the way in which the autoxidation chain reaction is initiated, which, in turn, depends on the presence of photoinitiators in the polymer (Grassie and Scott 1985).

Typical photoinitiators that have been used to sensitize the photodegradation of plastics in the outdoor environment after discard are listed in Table 2. Although many more have been reported in the patent literature, these are the only ones which have reached the marketplace. Companies producing them are also listed in Table 2.

Photodegradable plastics can be broadly classified into types:

- Copolymers in which the sensitizer, a carbonyl group, is built into the polymer.
- Conventional plastics to which the sensitizer is added, generally as a masterbatch and in some cases as a replacement for the usual processing stabilizer.

Copolymers

In the first approach, degradation occurs primarily by photolysis of the polymer backbone, leading to reduction in molecular weight and fragmentation of the polymer (Fig. 3). The Norrish Type II process is the predominant mechanism leading to chain scission, giving rise to ketone and vinyl groups at the end of the polymer chains (Grassie and Scott 1985). An early example of such a carbonyl-modified polymer was claimed in a patent by DuPont (Brubaker 1950), and this process has been commercialized relatively recently by DuPont and Union Carbide among others (Johnson 1987). The polymers embrittle rapidly and without any induction period (Harlen and Nicholas 1987; Statz and Dorris 1987), and if a period of

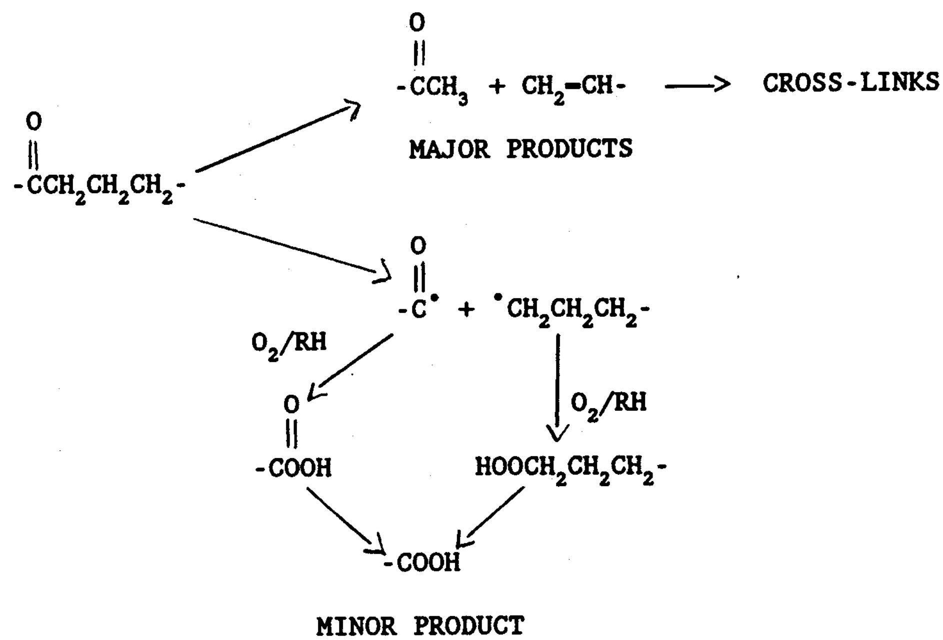


Figure 3.--Photolysis of in-chain carbonyl in polyethylene.

"safe" use is required, for example in storage or for a defined period out-of-doors, then the packaging has to be protected against UV irradiation. This kind of degradable plastic cannot, therefore, be used in agricultural protective film (mulch), where the polymer has to retain its strength for a well-defined period of time in sunlight but then has to photodegrade rapidly over a period of a few weeks. Rapid degradation appears to cease after all the in-chain carbonyl groups have photolyzed, and there is evidence (Harlen and Nicholas 1987) that the molecular weight decreases to a minimum and then increases again (Table 3). There is a similar minimum in the elongation to break, and these phenomena suggest that oxidation does not occur to any extent. This is consistent with the fact that if biodegradation does occur, it is extremely slow (Statz and Dorris 1987)--a considerable disadvantage of this type of product, since the fragmented products will still tend to accumulate in the environment.

In a more sophisticated approach to photodegradable copolymers, Guillet and his coworkers have copolymerized a variety of monomers, of which styrene, ethylene, and propylene are the most important, with vinyl ketones (Guillet 1973). These polymers have been commercialized under the name Ecolyte by Ecoplastics Ltd. (Redpath 1987). These polymers photolyze by essentially the same mechanism as the E/CO polymers, but both Guillet (Guillet et al. 1974; Jones et al. 1974) and Redpath (1987) have reported that the Ecolyte copolymers do biodegrade after fragmentation. This implies that the Norrish Type I process must play some part in initiating a conventional autoxidation chain reaction. However, the Ecolyte polymers suffer from the same disadvantage as the E/CO polymers in that they do not

Table 3.--Molecular weight changes in E/CO polymer (2.74% CO) on ultraviolet irradiation.

Exposure time, h	M_n	M_w
0	45,000	618,700
650	7,300	15,000
1,350	11,100	39,100

have a controllable induction period before rapid photodegradation commences.

Sensitizer Additives

In this approach, two main types of additive have been used. The first class falls broadly into the general class of triplet sensitizers, most importantly the benzophenones (Takahachi and Suzuki 1964) (see H. Omichi (1983) for a survey of the literature up to 1983). The mechanism of their action is summarized in Figure 4 and the related quinones act in the same way. Although the carbonyl sensitizers cause rapid photooxidation from the beginning of UV exposure, they autoretard rapidly in the case of

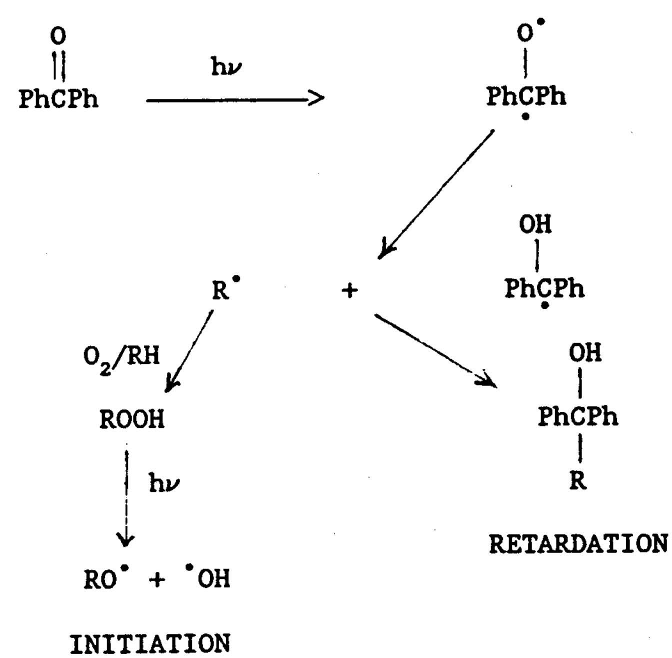


Figure 4.--Mechanism of photoinitiation and autoretardation by triplet sensitizers.

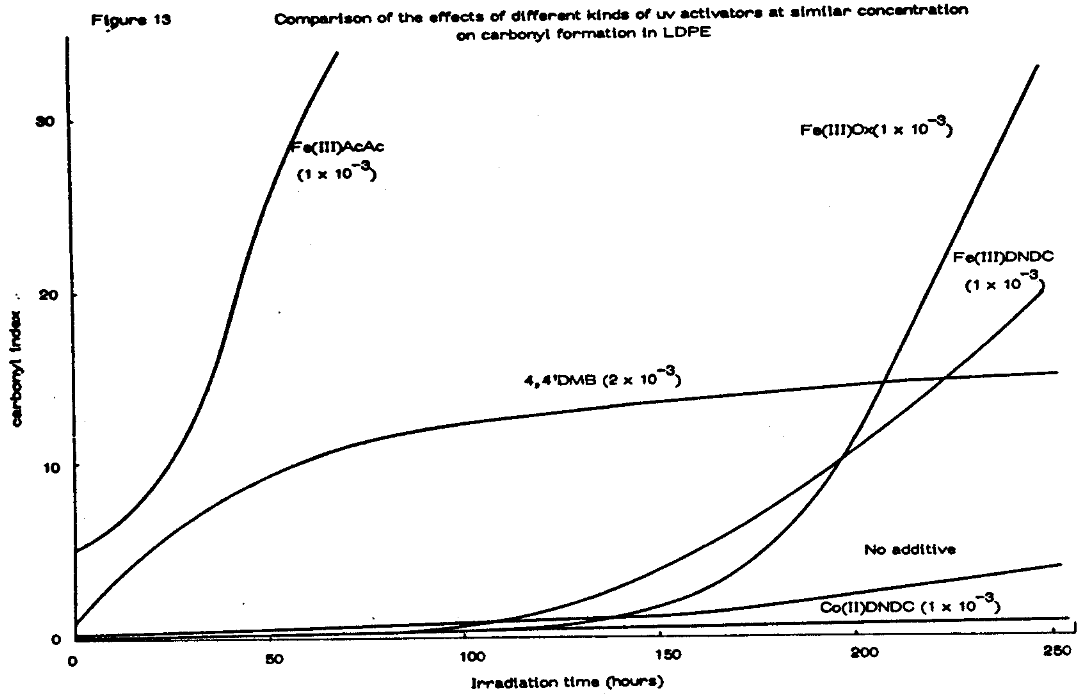


Figure 5.--Comparison of the photooxidation, as measured by carbonyl formation (at 1,710 cm^{-1}), of low density polyethylene (LDPE) films containing different kinds of photoactivator at similar concentrations. 4,4'DMB, 4,4'dimethoxybenzophenone; Fe(III)AcAc, iron acetyl acetonate; Fe(III)DNDC, iron dinonyl dithiocarbamate; Fe(III)L2, iron complex of 4-methyl-2-hydroxyacetophenone oxime; Co(II)DNDC, cobalt dinonyl dithiocarbamate (UV stabilizer). (From Amin and Scott (1974) with permission.)

polyethylene and the photooxidation virtually ceases after a period of time (Fig. 5) (Takahachi and Suzuki 1964). This is because the hydrogen abstraction step in Figure 4 leads to a "stable" radical which is able to trap out the chain-carrying species formed in the photooxidation process. This has unfortunate consequences for the long-term oxidation and biodegradation of the polymer, and this, coupled with the lack of an appropriate time control mechanism, has resulted in no commercial developments with this type of sensitizer system.

The second class of photosensitizer additives is based on transition metal ion compounds and is the most important class in use today. Transition metal ions have been extensively studied as photosensitizers for polyolefins (Takahachi and Suzuki 1964; Mellor et al. 1973; Amin and Scott 1974; Chew et al. 1977). Many polymer-soluble metal carboxylates, notably Co^{3+} and Fe^{3+}, are powerful photoprooxidants which catalyze photooxidation right from the beginning of UV irradiation (Fig. 5), and in the form of polymer-soluble carboxylates or acetylacetonates they cause melt degradation of the polymer during processing (Amin and Scott 1974). They cannot, therefore, be used alone in polymers in conventional processing operations because of their unfortunate effect on the melt stability of polymer and on the shelf-aging behavior of the fabricated product. Although conventional antioxidants improve processing and aging characteristics, they also interfere with the photosensitizing effect of the transition metal ions (Mellor et al. 1973).

The photoinitiating mechanism of the transition metal salts involves photolysis to give the reduced form of the metal ion and a free radical:

$$FeX_3 \xrightarrow{h\nu} [FeX_2\ X^{\bullet}] \longrightarrow FeX_2 + X^{\bullet} \tag{1}$$

The anion radical readily abstracts a hydrogen atom from the polymer

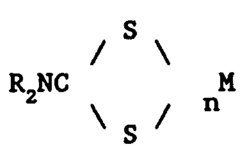
$$X^{\bullet} + PH \longrightarrow XH + p^{\bullet} \xrightarrow{O_2/RH} POOH \tag{2}$$

Once formed, hydroperoxides control the subsequent oxidative degradation by the usual redox reactions with metal ions, e.g.,

$$FeX_2 + ROOH \longrightarrow RO^{\bullet} + FeX_2OH. \tag{3}$$

Transition Metal Ion Antioxidant-Photosensitizers

Many metal complexes containing sulphur as a ligand are antioxidants and photostabilizers. Although this behavior is not limited to sulphur compounds, members of the latter class have gained a position of some importance as heat and light stabilizers for polyolefins (Scott 1965; Al-Malaika et al. 1983; Al-Malaika and Scott 1983). The dithiocarbamates (I) and the dithiophosphates (II) are representative of this class of stabilizers and exert their effect by destroying hydroperoxides by an



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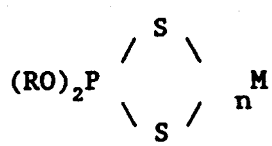

II

ionic mechanism (Al-Malaika et al. 1983; Al-Malaika and Scott 1983). One of their most striking and useful attributes is that they produce a well-defined and reproducible induction period during which the ligand is destroyed and at the end of which the metal ions which form part of the antioxidant are released and subsequently behave very much like the free transition metal ions described in the previous section (Fig. 5) (Scott 1965).

In 1971, Scott filed a patent based on the above concept in which antioxidant and photosensitizer properties were both contained in the same molecule, although this could be made in situ in the polymer by reacting the metal ion with the antioxidant (Scott 1971). The Fe(III) complexes of I and II are representative of this class of "delayed action" photoactivators. Not only do they replace conventional processing stabilizers by virtue of their antioxidant properties, but they are also effective heat stabilizers and short-term light stabilizers. The fact that the induction period to photooxidation could be controlled by varying the concentration of the metal complexes led in the early 1970's to the use of this system in agricultural mulching film, which requires a finely controlled lifetime before rapid photooxidation and biodegradation commences (Scott 1972b, 1972c, 1973a, 1973b, 1973c, 1975b, 1975c, 1976; Scott and Gilead 1978). This material was marketed as Plastor by Plastopil Hazorea, and subsequent development in collaboration with Gilead led to further patents (Scott and Gilead 1978) concerned with the fine control of the "safe" period, which is so essential for agricultural purposes (Scott and Gilead 1982).

The later developments involve the use of two component systems in which the length of the induction period is controlled by one metal thiolate and the rate of photooxidation by a second. The Scott-Gilead process is currently used in the commercial growing of soft fruits, vegetables, and some cereals in Italy, Germany, France, and the United States. In addition to the name Plastor, these products are sold under the trade names Greenplast (Enichem Agricultura, Italy), Plastigone and Litterless (Plastigone Technologies Inc., United States). The process is also used in polypropylene binder twine by the American Brazilian Company in the United States under the trade name Cleanfield.

The use of the Scott-Gilead system in agriculture has established the reliability of this technology. Figure 6 shows it in use near the Dead Sea in Israel. At the end of the induction period, the polyethylene film photodegrades rapidly, and biodegradation is complete by the beginning of the following season. There has been no buildup of nonbiodegraded plastics on any of the sites where it has been used.

In parallel with the above developments, trials began on the use of the original iron thiolate system in packaging. This led to the manufacture of carrier bags in Finland in 1973 under the name Ecoten. Figures 7 and 8 illustrate the progression of the degradation of Ecoten carrier bags exposed at intervals out-of-doors in Birmingham (Scott 1976). The time delay of about 2 weeks of summer sunshine before rapid degradation commenced was introduced at the request of the user to safeguard against adventitious exposure to light of the packaging during use. A measure of the effectiveness of the iron thiolates as thermal antioxidants is the fact that 15 years after their manufacture, carrier bags made by this process and stored in the absence of light are still as strong as when they were first manufactured. This process is currently being evaluated in check-out bags (United States), carrier bags (United Kingdom), and six-pack collars (United States), all of which tend to end up as litter.

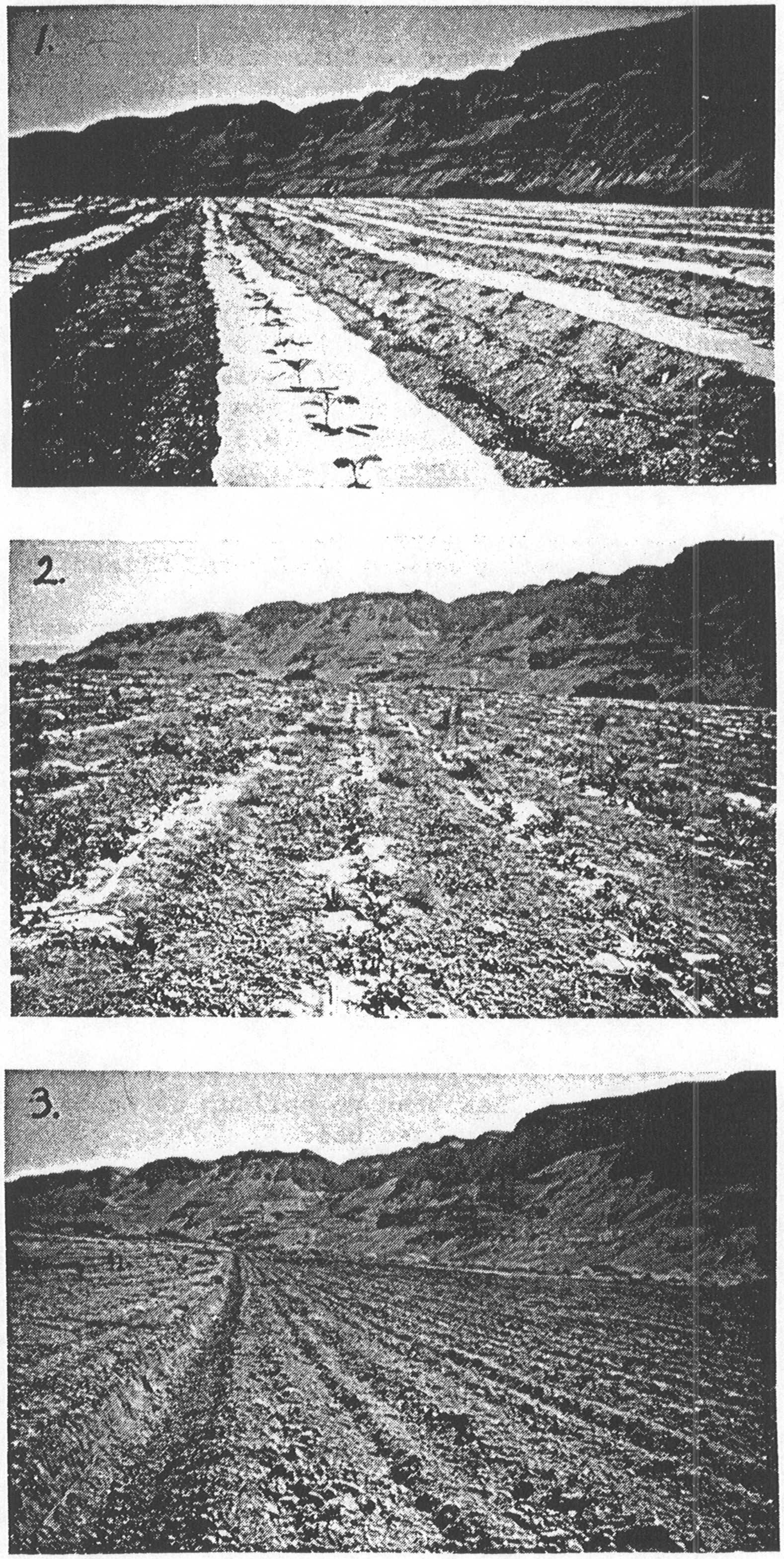

Figure 6.--Progress of photooxidation and biodegradation of Plastor (photobiodegradable) mulching film in Israel. 1--immediately after laying; 2--after cropping; 3--after ploughing. (Photographs by courtesy Plastopil Hazorea, Ltd.)

Figure 7.--Ecoten carrier bags exposed out-of-doors in Birmingham at 1-month intervals.

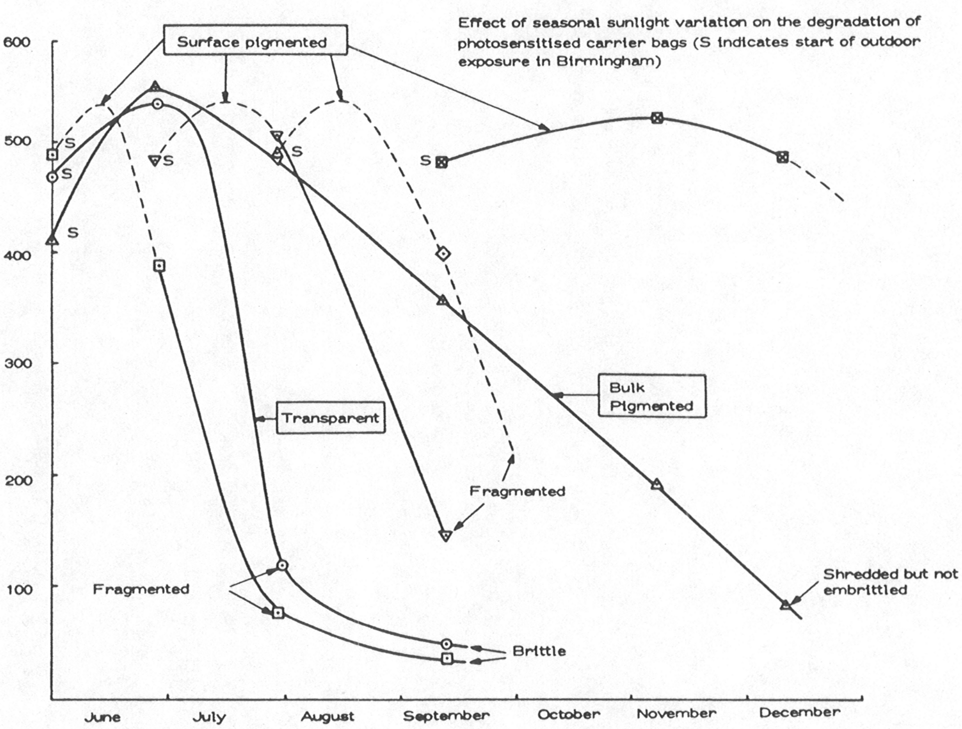

Figure 8.--Change in mechanical properties of Ecoten carrier bags exposed out-of-doors in Birmingham at 1-month intervals.

TECHNICAL REQUIREMENTS OF PHOTOBIODEGRADABLE PLASTICS

In spite of the successful use of photobiodegradable plastics in agriculture and to a lesser extent in packaging over the past 15 years, the packaging industry has been reluctant to accept them as a contribution toward the control of plastics litter. The arguments used against them are frequently couched in technical language, but are very often based on misconception rather than on technical fact and experience. The critics of degradable plastics are generally governed less by the published scientific evidence than by a reluctance to accept liability for the pollution resulting from the activities of their own industry. The pseudosociological arguments frequently used are intended as much for politicians as for the users of packaging.

The use of degradable plastics in agriculture was dictated by economic necessity. The same pressures are not evident in the use of degradable plastic in packaging, since rapid disintegration after use does not enhance the primary function of the package. Legislative bodies have, therefore, been reluctant to prohibit the use of nondegradable materials for purely aesthetic reasons. However, it is now clear that the situation is much more critical in the oceans, where there is a real threat to marine birds and animals. Experience in agriculture has unambiguously demonstrated that there are no economic or technical reasons why photobiodegradable plastics should not now be introduced into all bulk packaging. There is increasing evidence that the manufacturers and users of packaging are beginning to listen to the "green" movements, which advocate working with rather than against nature. The idea of returning waste plastics to the biological cycle is rapidly gaining popularity with the retailers of "organic" products and even with the large supermarkets.

However, packaging manufacturers are faced with a dilemma. The claims of the various degradation systems available are very difficult to check out. Furthermore, where they have been evaluated, the performance of some of the processes does not match up to the claims made for them. The terminology used is often confusing, and most technologists cannot distinguish between the subtleties of anaerobic and aerobic biodegradation, photodegradation, and photobiodegradation. There are at present no objective performance tests currently available which allow the user to compare the performance of degradable plastics. Until such criteria are available, it seems likely that the polymer industries will continue to argue on specious grounds against the introduction of more biocompatible, but also potentially more expensive, materials. In these circumstances, it seems unlikely that the polymer industries themselves will wish to fund the necessary research to establish the appropriate standards. The pressure for change must come from the users of packaging in association with the environmental pressure groups.

NET PACKAGING AND FISHING NETS

One of the most serious threats to marine life undoubtedly comes from ghost fishing, where both animals and fish become fatally entangled in

Table 4.--Combination effects of a photoactivator (FeDMC, 0.01 g/100 g) and a photostabilizer (NiDBC, variable) on the photooxidative stability of polypropylene.

Concentration of NiDBC, g/100 g	0	0.1	0.2	0.3	0.4
Embrittlement time, in hours	116	956	1,515	2,250	2,516

discarded nets. Much of this lethal debris arises accidentally by natural wear and tear on fishing gear, which has a finite life due to normal oxidative aging and biodegradation processes. Some of it, however, particularly in the packaging field, results from deliberate discard by the user. Most of the polymer used in these applications is polyolefin-based and so, as seen above, does not biodegrade rapidly unless sensitized to oxidation. An exceptionally wide range of lifetimes is thus required for netting, ranging from packaging, where ideally photobiodegradation should commence immediately on discard, to fishing net, where a service life of 5 years or more is required. This might at first sight appear to be an impossible achievement when coupled with the need for rapid photooxidation and biodegradation at the end of the useful life of the net. In practice, the Scott-Gilead system has been shown to be capable of providing this range of degradation times in polypropylene and high density polyethylene.

Table 4 shows that different combinations of photoactivator (FeDMC) and photoantioxidant (NiDBC) in polypropylene give a twenty-fivefold range of useful lifetimes (Scott and Gilead 1982), and more recent work has shown that this can be increased to a greater than fiftyfold range using a combination of different additives. In practice, this means that if a lifetime of 2 months is required for short-term packaging, then, using the same polymer but a different combination of the same additives, a lifetime of 8 years is technically feasible for fishing nets. This extraordinary lifetime control is accompanied in all cases by rapid photooxidation and biodegradation after embrittlement of the fiber. This process is already in commercial use in polypropylene binder twine (American Brazilian Company), where a lifetime of about 1 year is required followed by the rapid disappearance of the fiber from the field. It is fortunate that polypropylene, due to its low density, floats on the surface of water, where it is subjected to the combined effects of sunlight, oxygen, and microorganisms. This process is ideal for the protection of the environment from net packaging, ropes, and fishing nets which fail in service.

THE FUTURE

Polymer technologists have in the past been concerned to make sure that their products lasted as long as possible in the environment. It is increasingly being recognized that a more sophisticated approach is required in the future. Many products are required to last only as long as they fulfill their useful function, and the chemistry of stabilization has now advanced to the point where predictable lifetime control of polymeric materials is not only feasible but is now well proven through the pioneering activities of Gilead and his coworkers in plasticulture (Scott and Gilead 1982; Gilead 1985; Gilead and Ennis 1987).

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ENVIRONMENTAL DEGRADATION OF PLASTICS UNDER LAND AND MARINE EXPOSURE CONDITIONS

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ABSTRACT

Several types of thermoplastic and latex rubber materials commonly encountered in marine plastic debris were weathered outdoors in air and while floating in seawater, under North Carolina climatic conditions. The degradation of the different samples was monitored by tensile property determination.

In general, the various materials exposed outdoors in seawater tended to weather at a slower rate than the materials exposed outdoors in air. This retardation of weathering is probably a result of lack of heat buildup in samples exposed in seawater. Also, surface fouling on samples in seawater may have shielded them from light to some extent.

INTRODUCTION

In spite of their short history, synthetic polymers, particularly plastics, have gained wide popularity as the material of choice in a wide range of packaging, building, and other applications. With the current consumption of plastics reaching around 27.5 million metric tons (MT) (50 billion lb) in the United States (Modern Plastics 1988), plastics will without doubt continue to replace conventional materials such as glass, metal, wood, and paper in a variety of additional uses. The projected production in the year 2000 is expected to be 41.3 to 55.1 million MT (75 to 100 billion lb).

The popularity of plastics in packaging and other applications is attributed to the unique, useful characteristics of the material. These include light weight, excellent mechanical strength (tensile properties, tear resistance, and impact resistance), readily controllable and superior optical properties (clarity, gloss, and color), biological inertness, easy processability, low cost, and outstanding durability. Because they are synthetic materials, plastic compositions might be "tailor made," within limits, to obtain specific useful characteristics. As a response to an historically consistent consumer demand for stronger and longer lasting plastics, the industry has continually improved the durability of plastics, especially for outdoor exposure conditions.

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

The recent surge in the use of plastics as the material of choice in diverse applications is also reflected in uses of plastics at sea, particularly by the fishing industry. A very significant source of marine plastic debris is gear related. Introduction of plastics into the world's oceans started in the late 1940's with the changeover from natural fibers (jute, cotton, hemp) to synthetic polymer fibers in the construction of fishing gear (Uchida 1985). Today, nearly all the fishing gear used in developed countries is manufactured from durable synthetic materials (Klust 1973), and the commercial fishing industry is the prime source of plastics in the oceans.

In addition, passenger, freight, military, and research vessels, as well as beach users introduce plastic materials into the marine environment. Invariably, most of the non-gear-related plastic waste is discharged into the ocean as postconsumer waste from vessels or is washed into the ocean from the beach environment (Parker et al. 1987). The magnitude and the nature of this influx of plastics into the sea from such sources vary widely depending on the season of the year and the geographic region (Pruter 1987).

An inevitable consequence of increased usage of plastics, particularly in packaging applications, is the increased amounts of postconsumer plastic waste. The municipal waste stream (amounting to about >88,000 MT (160 million lb) annually in the United States) in urban areas now consists of about 7% postconsumer plastics, a figure that may increase to more than 9% by the year 2000 (Franklin Associates 1988). While accurate estimates of their lifetimes in the environment are not reliably known, plastics are perceived as being exceptionally persistent materials requiring hundreds of years of exposure to facilitate biodegradation.

Parallel estimates for the quantities of plastic waste in the world's oceans are not available. Estimates by several workers (Dahlberg et al. 1985; Pruter 1987), though probably very crude, allow an appreciation of the magnitude of waste at sea.

With a total annual world catch of about 45 million MT of fish (Parker et al. 1987), a substantial amount of plastic fishing gear is routinely introduced into the ocean. The estimates of worldwide losses of commercial gear vary from a low of about 750 MT tons annually (National Academy of Sciences (NAS) 1975) to as much as 75,000 MT/year (Merrell 1980). In addition to gear losses, fishing vessels also discharge "domestic" plastic waste. A 1986 estimate places the number of commercial vessels operating annually in the United States at 125,700 (Parker and Yang 1986). The world's fleet of fishing vessels is believed to discharge 23,000 tons of plastics annually into the sea (Horseman 1985).

A detailed discussion of the ecological concerns related to plastic debris at sea is beyond the scope of this paper. Several excellent reviews on the fate of plastic debris, the specific hazards posed by such debris in specific marine species, and the general impact of plastics on the populations of target species have been published (Day et al. 1985; Center for Environmental Education (CEE) 1987; Laist 1987).

Available evidence indicates entanglement by the debris and the ingestion of the debris to be the primary concerns with a variety of affected marine animals (including birds, turtles, marine mammals, and fish). These affected populations seem to seek out the debris (either mistaking it for prey or because of mere curiosity); such behavior leads to more fatalities than might be expected on the basis of random encounters with debris. The invariable association of either entangled fish or residual food in most of the plastic waste discharged into the sea also concentrates these species in the same geographic locations that have high incidences of plastic waste (Laist 1987). Recent declines in the natural populations of the Hawaiian monk seal, *Monachus schauinslandi*, by 4 to 8% per year have been attributed, at least in part, to entanglement in plastic waste (Fowler 1985, 1987).

PLASTICS AT SEA

Key Characteristics of Marine Plastic Waste

The potential negative impact of waste plastics on the marine resource depends upon the following key characteristics of the material.

- Geometry. Shape of the debris is important from the point of view of entanglement. Products such as six-pack rings and netting represent more of a potential hazard than an equivalent mass of the same polymer in the form of a laminate.

- Durability. The likelihood of encounter between a given item of marine debris and a marine animal depends upon the lifetime of the material. The duration available for the encounter is crucial in determining the potential hazard posed by the plastic material. Unfortunately, little information is available on the lifetime of plastics at sea. Lack of this information is a definite setback in the assessment of potential hazards posed by plastic waste.

- Strength. Strength of the debris material determines the likelihood that an entangled animal can escape. Alternatively, the possible obstruction of the gut in case of ingestion is less likely if the material is weak enough to mechanically fail during the ingestion process.

- Toxicity. Plastics, being undigestible macromolecules, cannot be absorbed through the gut lining. They are, therefore, not toxic materials. However, the plastics used in the fabrication of products may contain chemical additives which can be absorbed and assimilated.

Of these characteristics, lifetime is perhaps the most important. An attempt was therefore made in the present work to determine the relative lifetimes of some relevant debris items exposed on land and floating in seawater. The study will determine if the plastic materials floating on seawater degrade at rates different from those exposed to the same natural weathering conditions, but in air.

Weathering of Plastics Under Marine Exposure Conditions

Sunlight-induced degradation is the principal mechanism of weathering of plastics outdoors. As sunlight is freely available to plastics floating in the sea, weathering might be expected to occur at sea at rates comparable to those on land. However, there are several reasons to expect the rate of degradation at sea to be different from that on land.

- High humidity is known to accelerate the rates of degradation of several classes of plastics (Davis and Sims 1983). This may be brought about by the "plasticizing" action of small quantities of sorbed water leading to increased accessibility of the matrix to atmospheric oxygen or by the leaching out of stabilizing additives from the formulation.

- Plastics exposed to sunlight outdoors undergo "heat buildup," a process which results in the plastic material reaching significantly higher temperatures than the surrounding air (Summers et al. 1983). The higher temperatures generally result in an acceleration of light-induced degradation and may even be high enough to induce significant thermooxidative degradation. Plastics at sea will not suffer from such heat buildup and may consequently undergo slower oxidative degradation and photodegradation.

- All materials exposed to the sea invariably undergo fouling (Fischer et al. 1984). In the initial stages of fouling, a biofilm forms on the surface of plastic. Gradual enrichment of the biofilm leads to a rich algal growth within it. Consequently, the biofilm becomes opaque, and the light available to the plastic for photodegradation is restricted. Thus, the rate of photodegradation at sea might be determined in part by the rate of fouling.

- Advanced stages of fouling are characterized by the colonization of the plastic surface by macrofoulants such as bryozoans. The weight of the macrofoulant and that of debris they entrap might even partially submerge the material. As the ultraviolet portion of sunlight is attenuated on passage through seawater, submerged plastics would necessarily undergo a slower rate of photodegradation. Microbe-rich foulant film may, however, also tend to accelerate the biodegradation process by providing a rich biotic population in contact with the plastic surface.

DEFINITIONS DEVELOPMENT

An important issue relating to the discussion of degradability and enhanced degradable plastics is that of definitions. The various terms are used in a loose manner in the literature with no consistency. The need to develop adequate definitions has been pointed out recently by Andrady (1988) and others (General Accounting Office 1988). Definitions of the term "plastics" as it applies to the MARPOL Annex V Convention and the following terms relating to "degradability" are proposed as a starting point for further development.

For the purposes of MARPOL Annex V, the following definition of plastics has been proposed.

> Plastic: A solid material which contains as an essential ingredient one or more synthetic organic high polymer: and is formed (shaped) during either manufacture of the polymer or the fabrication into a finished product by heat and/or pressure.

The proposed definition includes both rubber and plastics (plastic products as well as virgin resin pellets). Inorganic polymers such as glasses are excluded along with low molecular weight polymers which are not "high" polymers or solids. The latter includes polymeric waxes, varnishes, and lubricants. The definition excludes any polymers produced by living organisms, including cellulose, natural rubber, and bacterial polyesters. In the case of a composite material where one component is a polymer, the material is excluded if the polymer itself is a minor component not essential to the formulation.

> Deterioration: Embrittlement and/or loss of physical integrity of a polymer regardless of the mechanism which brings about these changes.

The deterioration process might be the result of either a chemical or a physical process. Nonchemical deterioration of plastics plays an important role in environmental deterioration of plastics.

> Degradation: Deterioration which results from a chemical process.

Degradation might be further subdivided, based on the agency causing the chemical change. "Photodegradation" refers to degradation brought about by light. "Biodegradation" is that due to living organisms. Degradation due to slow oxidation of the plastic (especially at elevated temperatures) is "thermooxidative degradation," while that due to the chemical action of water is hydrolytic degradation or "hydrolysis." To be consistent with the definition for "degradation" proposed herein, it is necessary to show that a loss in property (in this case, tensile properties) occurred and that such loss is a result of a chemical reaction. The term "degradation" has been used throughout this paper without establishing that the loss was due primarily to a chemical change. However, the chemical nature of the processes which result in strength loss in plastics exposed to outdoor environments are well known.

The nonchemical deterioration processes might be similarly subdivided. "Dissolution" (or swelling in water), in which no chemical changes take place, might be viewed as a deterioration of the plastic in water (or an aqueous solution). "Biodeterioration" can take place when the plastic is attacked by borers (at sea) and rodents: The net result is the breakdown of a larger piece of plastic into small fragments. In "physical deterioration" a plastic loses strength due to purely physical phenomena (for instance due to freeze-thaw cycles).

This proposed scheme allows a facile classification of the related processes and makes a clear distinction between degradation which tends to chemically break down plastics, and nonchemical deterioration processes, which merely reduce the particle size of the plastic. The distinction is of obvious importance from an environmental point of view.

EXPERIMENTAL

Materials

The following plastic products, selected on the basis of reported composition of beach debris (CEE 1987), were included in this study:

- Polyethylene film (low density). Representative of the plastic used in six-pack rings, plastic bags, etc.
- Polypropylene strapping tape. Commercially available.
- Trawl netting material (orange and blue-green color).
- Latex rubber balloons. Commercial sample.
- Foamed polystyrene sheet. Commercial sample.
- Rapidly degradable polyethylene. Commercial sample.

Polyethylene bags are a well-known component of marine debris. The threat to marine turtles via ingestion of plastic bags has been reported (Balazs 1985). While strapping bands (usually made of polypropylene or polyester) are not a major component of the debris, they present a particularly severe threat of entanglement to marine mammals (Laist 1987). Trawl webbing is a major component of floating plastic debris in some regions (Pruter 1987). A fraction of the latex rubber balloons released in promotional events may eventually reach the oceans, where their ingestion may present a threat to turtles and other species.

Weathering and Sampling

Experiments were carried out at the exposure facility at Duke Marine Laboratory in Beaufort, North Carolina. Figure 1 shows the ambient temperature of the seawater during the period of exposure and the air temperatures for the area as recorded by the National Weather Service.

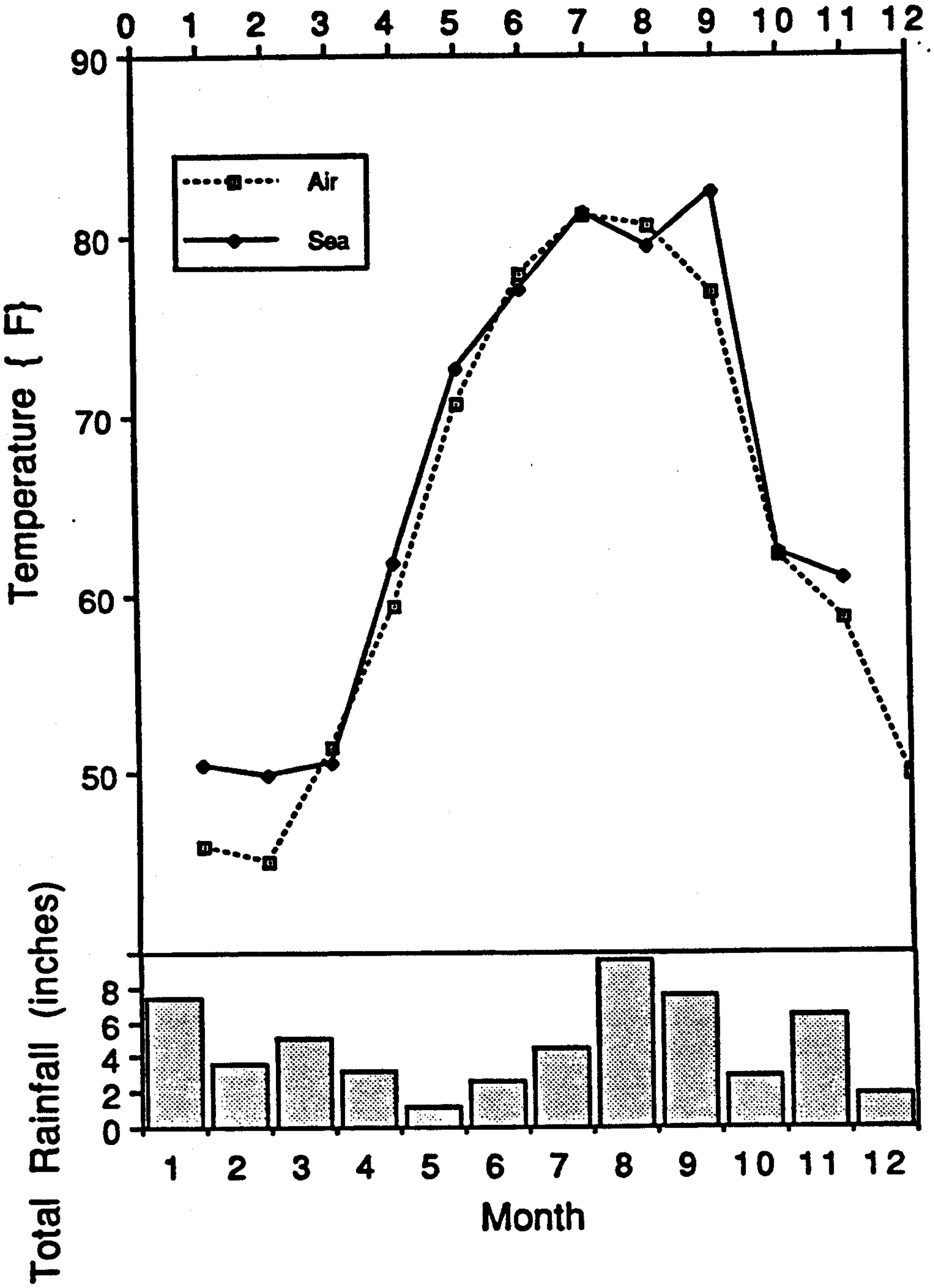

Figure 1.--Average monthly temperatures and rainfall for Morehead City, North Carolina for 1987.

The samples exposed on land were affixed with staples to a wooden platform and exposed horizontally on the flat roof of a laboratory building. These were backed by wood and were about 15.2 cm (6 in) from the roof surface. Another set of samples was exposed floating in a tank of seawater, with fresh seawater continuously flowing through the tank to maintain a depth of about 30.5-45.7 cm (12-18 in) of water at all times. Exposure in the tank as opposed to directly at sea has several associated advantages.

In the preliminary experiments carried out with samples directly floating in an enclosed section of sea, the samples tended to accumulate mud and debris on the surface due to tidal action. Exposure within the tank ensured minimal accumulation of soil and other floating debris on the sample while providing a fresh, clear, biologically active seawater medium. The experiment thus simulates the conditions best suited for rapid photodegradation. The exposure was carried out for a period of 1 year.

Sampling was carried out at the end of every second month for all samples. The exposed samples were placed in a black plastic bag and transported to the Research Triangle Institute for measurement of tensile properties. The samples exposed at sea were dried for about 3 h in an air oven at 50°C and were stored in the dark at ambient temperatures.

Tensile Testing

Measurement of tensile properties was carried out with an Instron Mechanical Tester, Model 1122 generally in accordance with ASTM D 638 (American Society for Testing and Materials) Tensile Properties of Plastics. No further preconditioning of the samples was done prior to testing. Air-powered grips were used to hold the samples. Smooth grip faces were used with the polyethylene samples; for latex balloons and strapping tape, a serrated face had to be used to avoid slippage. Table 1 gives the test parameters for various types of samples tested. In the case of trawl webbing and strapping tape, where the fibrous nature and surface markings, respectively, made it difficult to determine the true area of cross section, the load to break is reported.

RESULTS AND DISCUSSION

Polyethylene Film

Table 2 summarizes the tensile property data for the polyethylene film samples exposed on land and at sea. Both the sea and air samples exhibit an increase in tensile strength after 2 months. This increase may be due in part to relaxation of stresses frozen into the sample during processing, a common occurrence during early exposure of processed thermoplastics.

Figure 2 shows the variation of ultimate extension with exposure time. Clearly, the samples exposed floating on seawater degraded at a much slower rate. The samples exposed at sea showed a 12% loss in ultimate extension after 12 months while the air-exposed samples lost 95% of the ultimate extension after only 6 months. Ultimate extension is considered a more

Test parameter[a]	A	B	C	D	E
Beam capacity (kg)	1,000	1,000	1,000	1,000	1,000
Full scale load (kg)	10	20,100	5	200	2/5
Crosshead speed (mm/min)	100	100	20	100	50
Gauge length (cm)	5	1.5	4	4	3
Clamp	Pneumatic	Pneumatic	Pneumatic	Pneumatic	Pneumatic
Jaw face size (in)	1 × 1.5	1 × 1.5	1 × 1.5	1 × 1.5	1 × 1.5

[a]A - Polyethylene film and degradable polyethylene, B - strapping tape, C - Styrofoam sheets, D - trawl netting, E - balloons.

appropriate parameter than tensile strength for measuring physical degradation since it reflects the brittleness and consequent tendency of the plastic to fragment. Statistical tests at the 0.05 level of significance showed no significant difference in mean ultimate extension values of the 2- and 12-month samples exposed at sea but did show a significant difference in mean ultimate extension of the 2- and 6-month samples exposed in air.

Polypropylene Tape

Table 3 gives the summary data relating to the weathering of polypropylene strapping tape. The formulation contained a filler and the material was highly anisotropic, easily tearing along its length. Material did not "neck" on extension but ruptured gradually. As the surface of the tape was not smooth enough (because of an embossed pattern on the surface) to obtain an accurate value for thickness, the maximum load rather than tensile strength is reported. Figure 3 illustrates the observed changes in ultimate extension. After 12 months, samples exposed on land had lost 90% of the initial ultimate extension, while samples exposed at sea had lost only 26% of the initial value. Thus, while some degradation does occur in samples exposed on seawater, it is much less pronounced than that for samples exposed in air for a comparable duration of exposure. This conclusion is further illustrated by testing for the statistical significance of differences in mean ultimate extensions at the 0.05 level. A significant difference exists in mean ultimate extension for the samples exposed in air for 0 and 12 months and for those exposed at sea for 0 and 12 months. As expected, a statistically significant difference was also found between the mean ultimate extensions of the 12-month samples exposed at sea and in air.

Trawl Netting

Tensile property data for net samples are given in Table 4. The data are reported as maximum load (kg), which often coincided with the ultimate load of the material, and ultimate extension.

Table 2.--Summary of data relating to weathering of low-density polyethylene film samples.

Duration (months)	Tensile strength (kg/cm^2) Mean	S.D.	S.E.	Ultimate extension (%) Mean	S.D.	S.E.	Number of samples
Samples exposed in air							
0	124.1	19.6	6.1	548	71	29	6
2	143.1	9.9	4.4	541	38	17	5
4	99.9	5.1	2.9	188	166	96	3
6	115.8	6.5	3.3	27	18	9	4
Samples exposed in seawater							
2	139.5	17.1	7.7	613	133	59	5
4	131.0	12.8	5.7	547	95	42	5
6	132.3	23.6	13.7	601	197	114	3
8	117.3	13.4	6.0	511	147	65	5
10	117.8	7.3	2.9	550	106	46	6
12	118.7	7.6	3.4	541	87	39	5

Table 3.--Summary of data relating to weathering of plastic strapping tape.

Duration (months)	Maximum load (kg) Mean	S.D.	S.E.	Ultimate extension (%) Mean	S.D.	S.E.	Number of samples
Samples exposed in air							
0	75.5	2.0	1.0	82	2	1	4
2	68.2	1.7	0.8	70	7	3	4
4	40.2	5.2	2.6	43	4	2	4
6	20.1	3.2	1.6	19	5	2	4
8	14.9	3.5	1.8	12	4	2	4
10	13.2	2.7	1.4	10	5	1	4
12	11.3	0.7	0.4	8	1	1	3
Samples exposed in seawater							
0	76.5	5.4	2.7	89	5	2	4
4	77.0	4.0	2.0	91	3	2	4
6	74.3	2.5	1.3	82	2	1	4
8	73.2	5.6	2.8	79	5	3	4
10	64.0	5.2	2.6	63	8	4	4
12	67.2	3.3	1.6	61	9	4	4

Note: Sample width was half the size of regular width of the tape.

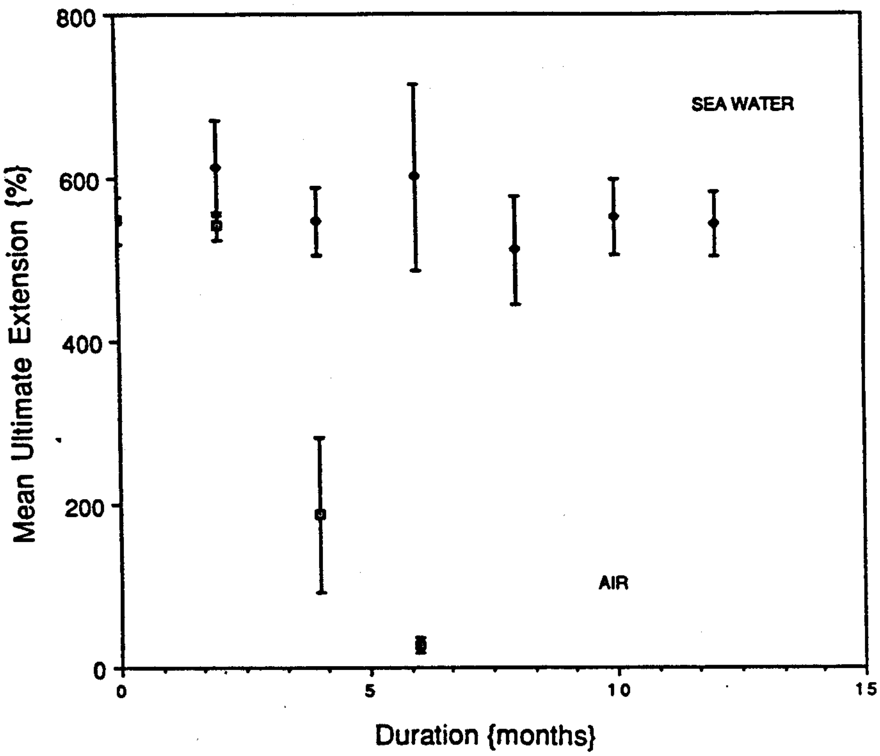

Figure 2.--The variation of the mean ultimate extension of polyethylene films with the duration of exposure.

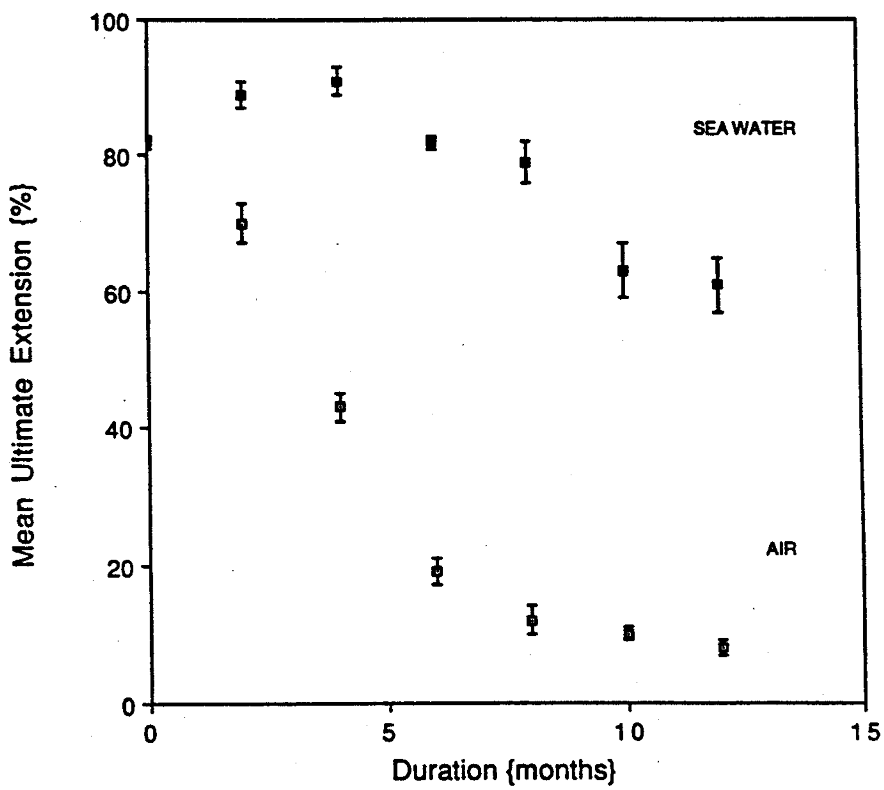

Figure 3.--The variation of the mean ultimate extension of polypropylene tapes with the duration of exposure.

Table 4.--Summary of data relating to weathering of trawl web material.

Duration (months)	Maximum load (kg) Mean	Maximum load (kg) S.D.	Maximum load (kg) S.E.	Ultimate extension (%) Mean	Ultimate extension (%) S.D.	Ultimate extension (%) S.E.	Number of samples
Orange-colored netting							
Samples exposed in air							
0	126	3.8	1.9	46.5	4.8	2.4	4
2	121	13.8	6.9	36.9	2.7	1.4	4
4	120	10.6	7.5	41.0	5.9	4.2	3
6	117	9.3	4.7	41.7	5.6	2.8	4
8	125	4.0	2.0	47.4	1.7	0.9	4
10	121	7.7	3.9	47.7	6.5	3.2	4
12	125	8.5	4.3	49.1	8.4	4.2	4
Samples exposed in seawater							
4	132	9.1	4.6	62.1	3.8	1.9	4
6	123	13.4	6.7	49.1	4.1	2.1	4
8	129	6.7	3.3	53.5	2.9	1.4	4
10	128	10.7	5.4	53.5	2.9	1.4	4
12	127	11.6	5.8	49.1	3.9	2.0	4
Blue-colored netting							
Samples exposed in air							
0	115	10.5	5.2	63.0	7.1	3.5	4
2	88	11.4	5.7	41.4	2.9	1.5	4
4	104	7.9	4.0	46.6	8.2	4.1	4
6	96	11.3	5.7	49.1	8.6	4.3	4
8	70	12.1	6.1	32.3	10.9	5.5	4
10	93	7.3	3.7	44.5	3.5	1.7	4
12	94	3.8	1.9	49.5	5.0	2.5	4
Samples exposed in seawater							
2	100	12.0	6.0	65.7	9.9	5.0	4
4	96	9.2	4.6	53.4	9.8	4.9	4
6	99	7.3	3.6	60.2	2.5	1.3	4
8	101	7.5	3.8	61.6	5.8	2.9	4
10	113	2.8	1.4	61.8	5.3	2.7	4
12	104	3.2	1.6	60.4	1.4	0.7	4

The changes in tensile properties obtained with trawl web samples on exposure in air and in seawater are less dramatic and are not shown in a figure. Netting intended for commercial fishing is compounded specifically for exceptional durability usually using hindered-amine and other light stabilizers. The data, however, did show that the blue netting is relatively more prone to outdoor degradation than is orange netting when exposed in air. While the difference is small, it is significant. On exposure in seawater, neither material underwent any significant change in maximum load up to 12 months of exposure (at which time the experiment was discontinued). The only conclusion that might be drawn from these samples is that they would persist longer in the environment, relative to the packaging materials and balloons tested.

Rubber Balloons

The strength and extensibility of the rubber balloons determine to a great extent the likelihood of the ingested material obstructing the air or gut passages of turtles. Retention of elasticity is of particular concern, as elastic materials are likely to be difficult to dislodge from the air passages or alimentary canals. Table 5 summarizes the tensile property data on balloons exposed under present experimental conditions. Figure 4 shows the variation of ultimate extension with duration of exposure. In air, the rubber lost 59% of its ultimate extension after only 2 months. For the same time at sea, the rubber lost only 11% of its ultimate extension. The balloons continued to retain their elasticity during exposure in seawater, with only a 48% loss after 12 months. In air, however, the balloons lost 94% of their ultimate extension after 6 months, beyond which time the samples were too weak and brittle to be tested. As with the plastic samples, the rate of degradation in seawater was much slower than that in air. The degree of hazard associated with a partially deteriorated balloon depends on the particle size which might be safely ingested by the target species. Such information on turtles and other relevant species is not available at the present time. However, the above results indicate that if the balloons do pose a hazard to marine life, they would, under present experimental conditions, be a threat for a relatively longer period of time at sea than on land.

Polystyrene Foam

In view of the abundance of polystyrene foam pieces in marine debris, the weathering behavior of polystyrene was particularly interesting. On exposure in air the foam underwent rapid yellowing, which apparently was a surface reaction. The sample exposed on seawater also underwent yellowing, although the algal fouling of the surfaces made it difficult to measure the extent of yellowing.

The yellowness index increased up to about the sixth month of exposure and decreased thereafter. However, the development of yellowness was also accompanied by embrittlement of the exposed surface. Over the exposure period of 1 year, a surface layer of up to half the original thickness became brittle enough to crumble on handling (and could be easily scraped out). Wind and rain are likely to remove at least some of the yellowed material during exposure. This may explain the reduction in the extent of yellowing at the longer exposure times.

Table 5.--Summary of data relating to weathering of latex rubber balloons.

Duration (months)	Tensile strength (kg/cm^2)			Ultimate extension (%)			Number of samples
	Mean	S.D.	S.E.	Mean	S.D.	S.E.	
Samples exposed in air							
0	96.7	7.2	3.6	986	100	50	5
2	3.6	1.9	0.9	405	184	92	4
4	1.9	--	--	140	--	--	2
6	1.4	--	--	63	--	--	2
[a]8	--	--	--	--	--	--	--
[a]10	--	--	--	--	--	--	--
Samples exposed in seawater							
2	22.7	3.4	1.5	874	107	48	5
4	21.5	5.4	2.4	727	75	34	5
6	16.0	3.1	1.5	611	69	34	4
8	14.0	3.6	1.8	600	87	44	4
10	18.3	3.5	1.7	719	74	37	4
12	9.1	1.0	0.6	513	26	15	3

[a]Too brittle or weak to be tested.

The yellowness index of the degraded polystyrene foam correlates well ($r = 0.90$) with the tensile strength of the degraded material up to 6 months of exposure in air. Lack of such a correlation at longer exposure times is also possibly due to loss of embrittled yellow surface material (from rain, wind).

In fact, the thickness of the degraded (removable) yellow surface layer increased with duration of exposure for both sets of samples. The reduced thickness of the samples after the embrittled layer was scraped off is given below.

Duration Months)	Thickness of lower layer (cm)	
	Air	Seawater
0	0.418	0.418
2	0.349	0.221
4	0.308	0.164
6	0.234	0.168
8	0.217	0.229
10	0.214	0.155

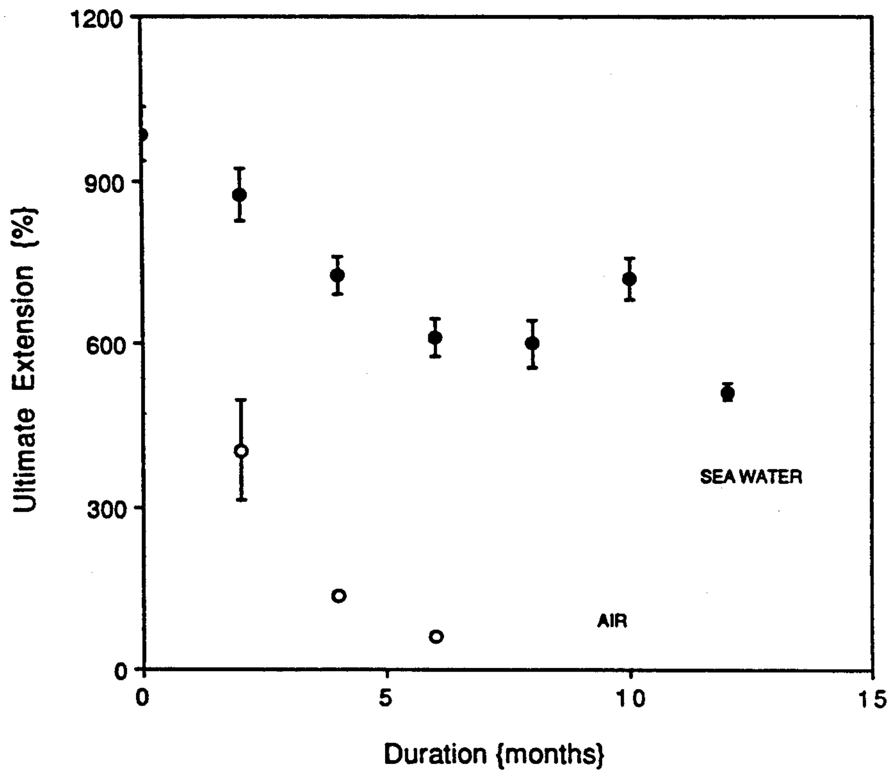

Figure 4.--The variation of mean ultimate extension of latex rubber balloons with the duration of exposure.

The tensile strength can thus be calculated in two ways: based on original thickness, and based on the thickness of the unembrittled layer. Table 6 summarizes the tensile property data. If the oxidative degradation process was restricted to the yellowed brittle surface layer, the tensile strength of the underlying polystyrene would yield about the same tensile strength regardless of the duration of exposure. However, as seen in the table and in Figure 5, the tensile strength based on reduced thickness of the material also decreases with the duration of exposure. The lower unembrittled region is apparently accessible to the free radicals generated during the photo reaction.

Expanded polystyrene was the only type of plastic material tested where the rate of deterioration (of tensile properties) was faster at sea than on land. In air, the material requires an exposure of at least a year to decrease its tensile strength by 40%. Exposure in seawater reduces the tensile strength by over 60% in 4 months!

Under the present exposure conditions, the polystyrene foam material deteriorates relatively rapidly when exposed outdoors on seawater. This would lead to the breaking up of the material into smaller pieces fairly easily. Unlike most other plastic debris items, pieces of foamed polystyrene are not capable of entanglement. They might, however, be ingested by a variety of species, especially when covered with foulants. Effects of ingestion of weathered polystyrene foam material are not known.

Table 6.--Summary of data relating to weathering of expanded-extruded polystyrene.

Duration (months)	Tensile strength[a] (kg/cm^2) Mean	S.D.	S.E.	Tensile strength[b] (kg/cm^2) Mean	S.D.	S.E.	Ultimate extension (%) Mean	S.D.	S.E.	Number of samples
Samples exposed in air										
0	3.89	0.50	0.21	3.89	0.50	0.20	3.9	1.70	0.07	6
2	4.31	0.34	0.17	5.16	0.40	0.20	3.5	0.29	0.14	4
4	3.46	0.59	0.29	4.70	0.80	0.40	3.9	0.32	0.16	4
6	2.45	0.27	0.19	4.37	0.48	0.24	2.9	0.13	0.06	4
8	2.39	0.27	0.19	4.60	0.52	0.26	3.2	0.24	0.12	4
10	2.61	0.14	0.07	5.09	0.27	0.14	3.2	0.24	0.12	4
12	2.37	0.27	0.19	4.53	0.51	0.25	3.3	0.32	0.16	4
Samples exposed in seawater										
2	2.88	0.21	0.09	5.45	0.40	0.18	4.6	0.80	0.36	5
4	1.13	0.71	0.36	5.50	1.82	0.91	4.1	1.60	0.80	4
6	1.09	0.17	0.09	3.20	0.44	0.22	2.2	0.88	0.44	4
8	1.22	0.29	0.13	2.22	0.54	0.25	1.9	0.29	0.13	5
10	0.69	0.09	0.04	2.13	0.22	0.11	1.6	0.24	0.12	4

[a]Tensile strength calculated using the initial area of cross section.
[b]Tensile strength calculated using the area of cross section based on residual unembrittled layer.

Enhanced Photodegradable Polyethylene (Ethylene Carbon Monoxide Copolymer)

The weathering behavior of the enhanced degradable polyethylene was quite different from that of the polyethylene homopolymer sample (Table 7). As might be expected, the samples exposed in air rapidly degraded, losing nearly 99% of the initial value of mean ultimate extension within 6 weeks of exposure (Fig. 6). The tensile strength decreased slowly reaching to about 50% of the initial value in the same period of exposure. At this stage samples were embrittled and too weak to be tested.

The samples exposed in seawater also degraded rapidly on exposure losing nearly 95% of the initial value of mean ultimate elongation in about 6 weeks. However, the material did not reach the same stage of final embrittlement obtained with samples in air until after 14 weeks of exposure. The mechanism leading to a plateau in the mean extension values from about the sixth to fourteenth week of exposure is not understood. But it is of little practical consequence. It is clear that under the experimental conditions of the study, the enhanced photodegradable polyethylene performs

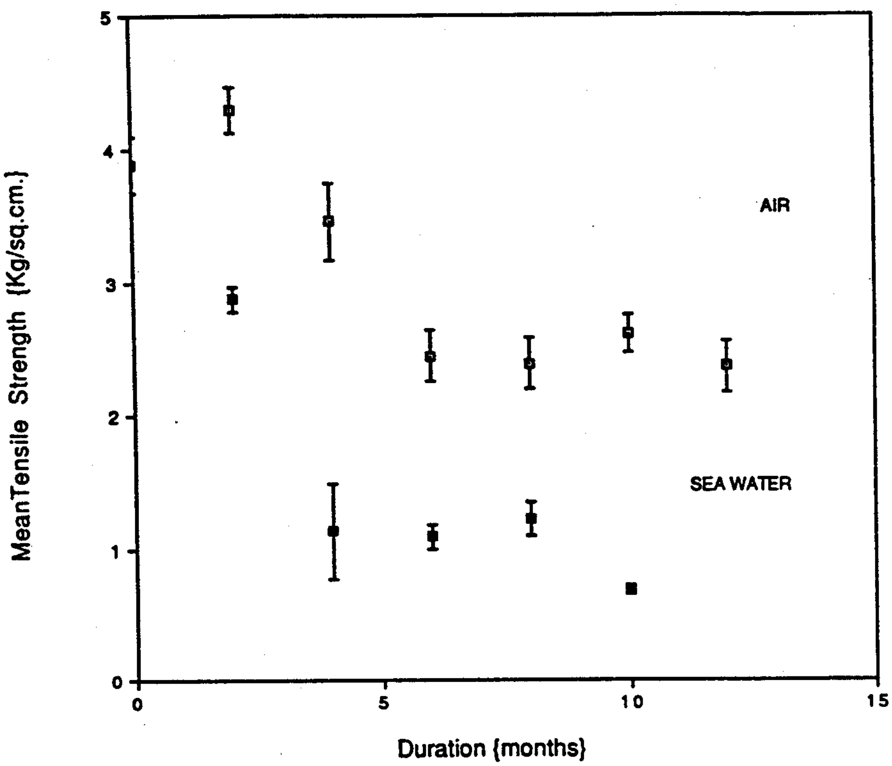

Figure 5.--The variation of mean tensile strength of expanded extruded polystyrene with the duration of exposure.

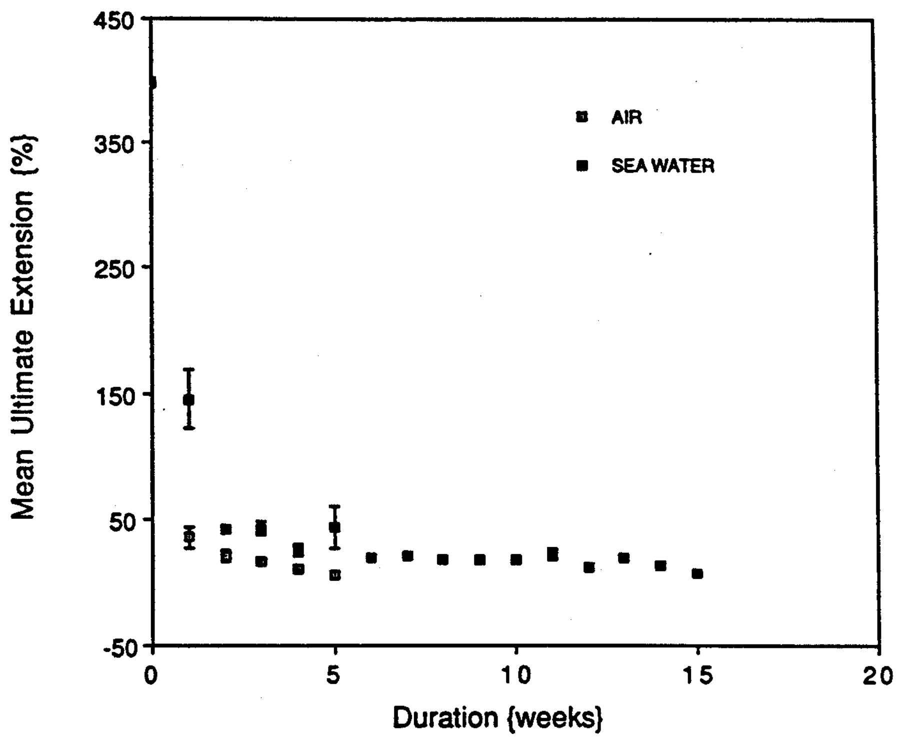

Figure 6.--The variation of mean ultimate extension of enhanced degradable polyethylene sheets with the duration of exposure.

Table 7.--Summary of data on outdoor weathering of enhanced photodegradable six-pack ring material (LDPE).

Duration (weeks)	Tensile strength (kg/cm^2) Mean	Tensile strength (kg/cm^2) S.E.	Ultimate extension (%) Mean	Ultimate extension (%) S.E.
Exposure in air				
0	160.4	1.0	398	3.4
1	122.4	2.1	35.6	8.3
2	128.0	2.4	21.0	4.4
3	134.1	2.4	16.8	1.4
4	104.7	8.0	10.7	2.6
5	86.3	6.9	5.7	0.8
Exposure in seawater				
0	160.4	1.0	398	3.4
1	112.0	3.7	145.6	23.3
2	112.3	1.0	42.4	3.3
3	115.1	0.8	42.3	5.4
4	120.4	0.9	25.8	4.1
5	116.5	2.6	44.1	16.7
6	120.2	12.6	19.1	1.0
7	122.9	0.8	21.0	3.1
8	121.1	0.4	17.71	0.5
9	119.7	2.8	18.4	1.4
10	122.6	0.5	18.1	0.6
11	122.8	0.5	22.6	5.1
12	116.3	5.7	11.3	1.3
13	119.1	14.0	19.4	0.8
14	73.77	21.8	13.9	2.2
15	58.9	6.6	6.9	1.7

satisfactorily at sea for all practical purposes. The initial rates of decrease in the mean tensile properties obtained with exposure in seawater, are somewhat slower than those obtained with exposure on land.

SUMMARY FINDINGS

Table 8 illustrates the general findings of the exposure study by a comparison of tensile properties before and after exposure in air and in seawater for the different samples. Data relating to a single duration of exposure are shown to illustrate the general trend observed. Except for the netting, rates of degradation for the samples in seawater were much

Table 8.--Comparison of weathering data for exposure on land and at sea.

Sample	Duration of exposure (months)	Percent decrease in the mean value of tensile property			
		Air		Seawater	
		Strength[a]	Extension	Strength[a]	Extension
Polyethylene film	6	6.6	95.1	No change	No change
Polypropylene tape	12	85.0	90.2	11.0	31.5
Latex balloons	6	98.6	93.6	83.5	38.0
Expanded polystyrene	10	32.9	18.0	82.3	65.2
Netting	12	No change	No change	No change	No change
Rapidly degradable polyethylene	1.25	46.2	98.6	27.1	88.9

[a]The percentages reported as based on the maximum load in the case of netting and polypropylene type materials.

slower than the degradation rates on land. Netting material did not show any significant variation in tensile properties due to the type or duration of exposure. Enhanced degradable polyethylene six-pack ring material degraded in about the same time scale under both air and seawater exposure.

The marked retardation of the weathering process observed in some types of plastic materials floating in seawater might be attributed to: (a) differences in heat buildup and (b) fouling of samples in seawater.

A significant fraction of the sunlight impinging on a plastic surface is absorbed by the material as heat. Depending on the nature of the plastic, the velocity of the air around it, and the temperature difference between the plastic and the surroundings, this absorbed energy maintains the plastic at a temperature higher than that of the surrounding air (Summers et al. 1983). Plastics exposed in air undergo heat buildup easily. The effect is even more pronounced in the present samples, which were exposed on a thermally insulating wood surface. Under such conditions, the heat buildup is likely to be higher than for the case of exposure on soil, thus simulating weathering under "worst case" conditions and accelerating the degradation process in the samples exposed in air. Samples exposed in seawater, however, are held at near ambient temperature leading to slower rates of degradation.

Samples floating on seawater underwent extensive fouling during the exposure. Foulants were mostly algae except for several *Balanus* sp. found on samples exposed for over 8 months. The experimental method used in the present study (containment of samples in a shallow tank) is likely to have reduced the extent of fouling and prevented the settlement of debris (or "silting") on the sample surface. Fouling retards the photodegradation by restricting the light available to the plastic.

CONCLUSIONS

Under present experimental conditions, low density polyethylene film, polypropylene tape, and latex rubber balloon samples were found to significantly degrade when exposed in air outdoors. Marked decreases in ultimate extension were obtained in 1 year of exposure. Similar samples exposed at the same site, but floating on seawater, degraded at a significantly slower rate during the same period of time.

The lower rates of degradation might primarily be attributed to lack of heat buildup in samples exposed on seawater. Biofouling of sample surface leading to reduced light availability may also have decreased the rate of weathering.

Foamed polystyrene degraded at a faster rate in seawater than in air when exposed outdoors.

Enhanced degradable six-pack ring polyethylene degraded at nearly the same rate when exposed in air and in seawater.

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RECYCLING OF MARINE PLASTICS DEBRIS THROUGH MELT REPROCESSING: A CASE FOR LOST OR ABANDONED FISHING GEAR

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ABSTRACT

In attempts to offer a technological solution to the marine plastic debris problem, the Polymer Processing Institute in collaboration with the New Jersey Marine Sciences Consortium began in January 1989 a 2-year research program that focuses on the collection, characterization, and subsequent recycling of unusable plastic fishing gear. The present paper contains initial data developed during the first quarter of 1989 (Phase I) on netting containing nylon-6, nylon-6,6, and polypropylene plastics. Molecular weight determination and thermal analysis suggest that none of the nylons are badly degraded; thus, the nets could be reprocessed without difficulties in the recycling extruder. However, the presence of fiber coatings (e.g., "green enamel," "tar") was found to complicate the polymer characterization and to interfere with the recycling process. The fact that these coatings cannot be easily removed suggests that further work is required to determine their possible adverse effects on the processing and product characteristics. The present paper also provides a complete description of the work planned for the two successive phases of the project.

INTRODUCTION

Among the various marine plastic debris items, abandoned or lost fishing gear is a major pollutant adversely affecting marine life and disturbing the ecological equilibrium. Recent estimates of the National Academy of Sciences bring the amount of fishing gear lost in the sea to about 135,000 metric tons/annum (Lautenberg 1987). Many marine species die from entanglement in such plastic debris. It is believed that 30,000

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

northern fur seals, *Callorhinus ursinus*, and at least 250,000 birds die each year in nets laid by salmon fishermen, as well as in other debris. The problem appears to become increasingly important as a result of the recent deployment in the North Pacific of huge drifting nets stretching up to 30-50 km (Shabecoff 1989). If these lightweight monofilament nets are discarded or lost, they do not degrade but continue to drift unless retrieved.

The Polymer Processing Institute, in a joint effort with the New Jersey Marine Sciences Consortium (NJMSC), began in January 1989 a 2-year program having as an ultimate goal the development of cost-effective methods for complying with the prohibition of marine pollution. The project is funded by the Saltonstall-Kennedy Act and will attempt to offer a technological solution to the marine plastic debris problem. Its specific objective is to establish incentives for recycling lost or abandoned fishing gear such as nets, lines, and ropes by demonstrating that these materials can be converted into useful products when melt reprocessed.

DESCRIPTION OF THE RESEARCH PROJECT

This project consists of two phases: Phase I, completed in January 1990, concentrates on the collection, on a national level, of discarded fibrous fishing gear, followed by separation, identification, and subsequent chemical and physical characterization of the plastics involved. Preliminary data indicate that the major types of plastics to be recovered are nylon-6, nylon-6,6, and polypropylene (PP), all possibly contaminated or degraded as a result of prolonged exposure in the marine environment. The extent of environmental degradation and its effect on rheological and mechanical properties will dictate the design of the melt reprocessing experiments of the next phase.

In Phase II of the project (to be completed in its second year), various processing methods will be evaluated with the final objective of producing molding materials with properties equivalent or superior to those of virgin resins. Reprocessing will be conducted in a twin-screw extruder and will involve blending of the recovered netting with virgin resin, blending with other recycled resins of different chemical structure, or chemical modification. It is expected that these methods will upgrade the properties of the recovered plastics and produce value-added compounds. At this stage of the project, potential markets for the recycled product will be identified as well as companies interested in establishing facilities for recycling and reprocessing. Based on the analysis of the collection and separation data, the possible financial incentives that will encourage recycling will be estimated.

EXPERIMENTAL RESULTS

Characteristics of Collected Fishing Gear

Samples of used and new fishing nets were supplied by NJMSC. The used samples that were collected during the first quarter of Phase I varied widely in characteristics such as net mesh size, filament diameter, type of coating, degree of exposure, polymer type, and site of collection. All samples were classified and characterized as shown in Table 1. The majority of the collected nets were relatively clean, with minimum visible gross contamination from either organic or inorganic matter.

Identification of Plastics and Contaminants

The identification of plastics and their contaminants was undertaken in order to establish the proper reprocessing conditions and to minimize any possible adverse effects of the contaminants on processing and long-term polymer stability.

Identification methods used for plastics were infrared (IR) spectroscopy, melting temperature determination, and solubility measurements (the latter only for nylons). The preferred analytical method was IR spectroscopy, since the presence of coatings (e.g., "green dip," "tar") often interfered with the melting temperature and solubility determinations. The IR spectra were obtained on films cast on a AgCl plate from solutions of 90% formic acid (nylons) or hot xylene (polypropylene). Table 2 summarizes the identification results for all plastics. It is shown that nylon-6 and nylon-6,6 are the materials of choice for nets, whereas polypropylene is used for ropes and lines. It is interesting to note that the green-dipped twine in 88-2 contained both nylon-6 and nylon-6,6 fibers; by contrast, the attached repair portion was only nondipped nylon-6,6 fibers.

A thorough analysis and identification of contaminants was not completed at this stage of the project. Some surface elements that were identified by combined scanning electron microscopy and energy dispersive x-ray analysis included silicon and iron on the 88-2 fibers. These could correspond to sand and rust, respectively. Also, the "green dip" on 88-2 and 89-2 and the tar coating of 89-1 contain infusible cross-linked organic materials that turn black (degrade?) when heated near the melting temperature of nylons. The coatings level was not precisely determined. Preliminary thermogravimetric data suggest that the green dip content is at least 3-5%, whereas the tar content is at least 1% of the weight of the fiber.

Separation of Individual Plastics and Removal of Contaminants

Separation of the individual identified plastics present in the nets or the net and line combinations was not considered necessary at this stage of the project, since the proximity in chemical structures and melting points could allow these polymers to be eventually processed as blends (e.g., nylon-6 with nylon-6,6 in sample 88-2, nylon-6 with PP in sample 88-3). Floats, buoys, and lead-containing lines were the only articles that were removed. With respect to contaminant removal, the insolubility of the "green dip" and "tar" coatings in either water or organic solvents appears to preclude their economical separation from the fibers. Also, any water treatment of the fibers by slurrying under agitation does not seem to be beneficial in improving their thermooxidative stability, as certain

Table 1.--Classification and description of used and new fishing gear received in 1988 and first quarter 1989.

Designation	Type or description	Color	Mesh (cm)/ diameter (mm)	Other information
Used				
88-1	Fyke(?) net with braided line attached; ca. 14 kg	Dark brown	Net: 7.5/1.2 Line: --/6.3	Brittle, dusty, badly degraded.
88-2	Trawl net, apparently dipped in green "enamel" and repaired with non-dipped net; ca. 50 kg	Dipped part: green or faded green Repaired part: off-white	8.3-10.5/3	Collected in New Jersey; variable in color, mesh and diameter; tar patches.
88-3	Monofilament gillnet with braided line attached; ca. 10 kg	Net: natural Line: green	Net: 8.3/0.37 Line: --/6.3	Collected in New Jersey.
89-1	Trawl net [30-ft flat otter] dipped in tar; ca. 25 kg	Black	4.5/1.2	Bought in Connecticut; used once per month for 1 year, stored in shed, repaired.
89-2	Trawl net [30-ft flat otter] dipped in green enamel; ca. 25 kg	Light green	3.8/1.2	Bought in Mississippi; used twice per month for 1 year, stored in shed.
New				
89-3-V	Twine net sample	Off-white	3.8/1.6	None.
89-4-V	Multifilament net sample	Light green	12.7/0.8	None.
89-5-V	Braided net sample	Light green	20/2.5	None.
89-6-V	Twine net sample	Blue	3.4/1.6	None.

Table 2.--Identification of polymers (by infrared spectroscopy, and solubility and melting temperature measurements) in used and new fishing gear.

Gear designation	Type of polymers
Used	
88-1	
Net	Not identified
Line	Not identified
88-2	
Green net	Nylon-6 and nylon-6,6
Faded green net	Nylon-6 and nylon-6,6
Repair net	Nylon-6,6
88-3	
Net	Nylon-6
Line	Polypropylene
89-1	
Net	Nylon-6
89-2	
Net	Nylon-6
New	
89-3-V	Nylon-6,6
89-4-V	Nylon-6
89-5-V	Polypropylene
89-6-V	Polypropylene

experiments showed. Thus, the only treatment prior to characterization was the removal of loose surface debris by air jetting.

Characterization of the Recovered Nylon Plastics

The characterization of the recovered plastics could provide valuable information on the extent of their degradation and their thermooxidative stability during reprocessing.

Table 3 summarizes the intrinsic viscosity and molecular weight data of all nylon polymers including three virgin materials in pellet form. Since the exact molecular weight of a fiber prior to exposure is not known, the extent of degradation can be only approximated. Thus, by comparing the intrinsic viscosities of the recovered polymers with those in the new nets and certain virgin pellets, one can conclude that with the possible exception of the "88-2 faded green" none of the other used nets showed extensive degradation of molecular weight. Thermal analysis (Table 4) by differential scanning calorimetry (DSC) and thermal stability investigations (Table 5) by thermogravimetry (TGA) tend to support the above conclusion. Differences in fusion and crystallization behavior between the fibers in the used or new net and the commercial pellets reflect largely the presence of

Table 3.--Intrinsic viscosity and molecular weight of nylon polymers: comparison of used and new fishing nets with commercial polymer pellets.

Sample designation	Intrinsic viscosity η^a(dl/g)	Molecular weight (M_v) Nylon-6		Nylon-6,6
Used nets				
88-2				
Green	1.45	[b]43,840	or	21,480
Faded green	1.07	[b]30,380	or	14,140
Repair	1.31			18,710
88-3	1.52	46,520		
89-1	1.42	42,660		
89-2	1.31	38,840		
New nets				
89-3-V	1.44			21,460
89-4-V	1.61	50,090		
Pellets				
Zytel 101-F	1.16			15,760
Capron 8207-F	1.47	44,730		
Capron BHS-D	1.70	53,440		

[a]η - Measured in 90% formic acid solution at 25°C.

[b]Figures given refer to the individual polymers since both nylons are present in these nets in unknown ratios.

Table 4.--Thermal analysis (differential scanning calorimetry (DSC)) of nylon polymers: comparison of used and new fishing nets with commercial polymer pellets. Note: Heating, cooling, and reheating at 20°C/min; fusion data on second heating.

Polymer	Fusion temperature onset/maximum (°C)	Heat of fusion (cal/g)	Crystallization temperature onset/maximum (°C)	Heat of crystallization (cal/g)
		Nylon-6		
Used nets				
88-2				
Green	211/222	10.7	187/181	-12.1
Faded green	212/223	10.9	187/182	-12.4
88-3	202/215	10.4	173/164	-11.4
89-1	208/221	8.3	181/174	-10.4
89-2	195/200	10.2	184/176	-12.0
New nets				
89-4-V	205/220	9.9	186/171	-12.1
Pellets				
Capron 8207-F	209/222	12.8	180/168	-13.4
Capron BHS-D	212/226	11.4	172/163	-10.7
		Nylon-6,6		
Used nets				
88-2				
Repair	253/263	16.2	231/227	-12.7
New nets				
89-3-V	250/259	11.8	229/222	-12.9
Pellets				
Zytel 101-F	256/265	11.3	226/214	-14.0

coatings, rather than extensive polymer degradation. For example, coatings and contaminants or their residues appear to act as nucleating agents, as evidenced by the higher crystallization temperatures of the polymers in all the coated used and new nets. Also, extensive weight losses in TGA are probably associated with the early decomposition of the coatings and contaminants and not with that of the degraded polymer itself (with the possible exception of the "88-2 faded green" sample). Table 5 also shows that the thermal stability of the samples is practically independent of the type of test atmosphere (nitrogen versus oxygen).

Table 5.--Thermal stability (thermogravimetry (TGA)) of nylon polymers: comparison of used and new fishing nets with commercial polymer pellets.

Polymer	Standard TGA[a]				Isothermal TGA[a]		
	Onset decomposition temperature (°C)		Temperature at 10% weight retention (°C)		Isothermal temperature (°C)	Weight % decrease after 15 min	
	Nitrogen	Oxygen[b]	Nitrogen	Oxygen[b]		Nitrogen	Oxygen
Nylon-6							
Used nets							
88-2							
Green	429	NM	560	NM	225	4.03	4.84
Faded green	396	NM	673	NM	230	1.35	1.48
88-3	445	NM	513	NM	225	0.33	0.42
89-1	459	NM	519	NM	230	0.91	1.06
89-2	426	NM	525	NM	230	2.71	3.49
New nets							
89-4-V	459	NM	513	NM	230	0.26	0.38
Pellets							
Capron 8207-F	466	453	513	497	225	0.25	0.25
Capron BHS-D	471	NM	506	NM	230	0.62	0.67
Nylon-6,6							
Used nets							
88-2							
Repair	449	NM	530	NM	270	1.18	4.31
New nets							
89-3-V	451	NM	514	NM	270	1.23	1.75
Pellets							
Zytel 101-F	439	436	503	512	270	0.33	0.58

[a]Standard TGA at 40°C/min; in isothermal TGA temperature reached withn 2 min..

[b]NM indicates not measured.

Experiments on Net Size Reduction and Extrusion Reprocessing

Attempts to chop net 88-2 into smaller pieces in a laboratory granulator were not successful even in the presence of dry ice. However, it was possible to feed continuously the same net into the hopper of a single-screw extruder and produce an extrudate that could be pelletized. The extrudate was black in color, presumably as a result of the decomposition of the fiber coating. Further experiments are under way in order to produce solid particles with dimensions suitable for feeding in polymer processing machinery such as extruders or injection molding machines.

CONCLUSIONS

The identification results on samples of unusable fishing gear collected during the first quarter of 1989 indicate that the major plastic involved are nylon-6, nylon-6,6, and to a lesser extent polypropylene. Th initial characterization results of the exposed nylons are encouraging: it appears that none of the nylons are badly degraded in terms of reduced molecular weight or loss of thermooxidative stability. This could mean satisfactory processing characteristics during remelting of the net in the recycling extruder. The presence of fiber coatings that cannot be easily removed tends to complicate not only identification and characterization, but also the reprocessing behavior of the nylon nets. Our future efforts will include the complete analysis and characterization of typical commercial fiber coatings for a better understanding of their effects on processing. Other research areas addressed during this phase of the project include the full characterization of the collected exposed polypropylene gear and the investigation of net size reduction methods.

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CONTROL OF PLASTIC WASTES ABOARD NAVAL SHIPS AT SEA

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ABSTRACT

The U.S. Navy is taking a proactive approach to comply with the prohibition on the at-sea discharge of plastics mandated by the Marine Plastic Pollution Research and Control Act of 1987. For U.S. naval ships, space and weight constraints, high crew densities, and mission requirements create unique solid waste management problems.

In pursuit of a zero discharge goal without significant adverse impact, processes, activities, operations, and systems to reduce plastics discharges are being identified, evaluated, and documented. Operational, supply, and technology-oriented solutions are now being demonstrated. Seven ships have been nominated by Commander in Chief U.S. Atlantic and Commander in Chief U.S. Pacific Fleets to participate in a plastics waste reduction demonstration project. Each ship was asked to develop its own instructions and procedures to eliminate the discharge of plastic wastes and to implement those instructions in a manner consistent with the operational requirements and mission of the ship.

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

Thus far, a submarine tender, a frigate, a destroyer, and two submarines have participated. Scientists and engineers from the David Taylor Research Center have collected waste generation rate and characterization data and have monitored and documented lessons learned. Naval Supply Systems Command has provided support for the demonstrations by recommending substitutes for plastic products, and new waste processing systems being developed by the Naval Sea Systems Command have been evaluated. Procedures for both the source separation of plastic and non-plastic wastes and the separation of food-contaminated plastic waste from non-food-contaminated plastic waste have been very successful aboard each of the demonstration ships. Plastic wastes have been stored and returned to port. A new Navy-developed vertical trash compactor has been successfully used to process plastic and nonplastic waste separately, and a pulper has been successfully used to process large volumes of degradable, nonplastic waste for ocean discharge.

SOLID WASTE: THE NAVY SHIPBOARD PROBLEM

For as long as ships have sailed the oceans, waste has been thrown overboard at sea. This practice continued unchallenged for centuries. The ocean's vast size and powerful assimilative capacity easily absorbed ship-generated waste with no apparent adverse impact. For many years, the waste consisted of simple degradable materials; later, the waste included metal, which sank. However, the relatively recent development of synthetic materials such as plastic, which float and persist in the marine environment when thrown into the sea, has changed the perception that there is no harm in discharging ship-generated trash at sea.

The visible evidence of ships' discharges now points an accusing finger at the maritime industry and the military for polluting the oceans, even though a great proportion of trash on the beach originates from sources ashore. Initially, the concern over marine debris, whether floating at sea or washed onto the beach, was because it offended our sense of aesthetics. However, as plastic became more pervasive in its application, other problems developed. Plastic line began to foul ships' propellers, and drifting plastic sheeting clogged ships' seawater intakes.

Floating marine debris also presented a unique problem for warships--it compromised security. Buoyant bags of trash establish a trail of floating waste which can betray a ship's location. Floating waste can be recovered more easily, enabling adversaries to gain information from the items contained therein.

Regulations of the U.S. Navy prohibit the discharge of any trash within 25 nmi of any shore, and require that all trash be weighted before disposal at sea to ensure that it sinks. However, it is difficult for shipboard personnel to consistently package or process waste for negative buoyancy without the use of special equipment.

In 1970, when the nation finally confronted the environmental crisis and sweeping clean air and water legislation was established, the Commanders in Chief of the Atlantic and Pacific Fleets recognized the need to develop strategies and technologies to deal with the solid waste problem. A comprehensive Naval Shipboard Refuse Study (NSRS) revealed that each person afloat generated about 1.4 kg (3.05 lb) of solid waste per day (Table 1). (Note that less than five thousandths of a kilogram per person per day was plastic waste.)

However, warships at sea had no holding capacity to store waste on board. Waste storage also created health and sanitation hazards and fire control problems. Overboard disposal by Navy ships continued to be the practice.

Recognizing that an alternative to overboard disposal was necessary, the Naval Sea Systems Command set out to find suitable solid waste processing systems. Initially, their goal was to process the degradable waste so it would not float when discharged and to compact the intrinsically heavy, inert material so it would sink to the bottom. This would eliminate the problems caused by floating debris. At the time, plastic waste was not viewed as a serious problem because of the small amounts generated aboard ship.

What seemed a simple concept in the early 1970's proved to be extremely difficult to execute. Commercially available equipment could not meet the rigorous requirements imposed by the Navy (Table 2). Dozens of candidates were evaluated at the Navy's David Taylor Research Center, but none could satisfy the demands of a warship. The first real equipment successes began when industry teamed with the increasing experience of the Navy, and a family of Navy-model food waste disposers was developed.

During the late 1970's, the Navy's engineering communities at the Naval Sea Systems Command and David Taylor Research Center initiated a long-term shipboard solid waste control research and development program.

RISING TIDE OF MARINE PLASTICS AND U.S. REACTION

Public concern over marine debris magnified enormously in the 1980's because of the terrible impact that synthetic material, particularly plastic, was having on marine life. The amount of floating marine debris continued to increase, creating more beach litter and overwhelming waterfront communities struggling to maintain a high-quality beach environment.

The increase in floating marine debris corresponded to the increased use of plastic products in the home, industry, and marketplace. Plastic and synthetic products found their way aboard maritime ships--and then overboard. Comparing studies conducted in 1971 and 1987, Table 1 shows an approximate twentyfold increase in Navy shipboard plastic waste. No prohibitions existed in the early 1980's against the discharge of shipboard-generated waste once a ship was beyond 3 nmi of the shoreline.

Table 1.--Generation of naval shipboard solid waste (kg (lb) per person per day).

Item	Naval shipboard refuse study - 1971	Naval shipboard refuse study - 1987
Plastic	0.004 (0.01)	0.095 (0.21)
Food waste	0.603 (1.33)	0.580 (1.28)
Glass	0.008 (0.02)	0.059 (0.13)
Metal	0.299 (0.66)	0.186 (0.41)
Rubber	0.004 (0.01)	0.004 (0.01)
Paper, other	0.463 (1.02)	0.503 (1.11)
Total	1.38 (3.05)	1.43 (3.15)

Table 2.--Criteria for naval shipboard waste processing equipment.

Parameter	Requirement
Reliability	High
Manpower	Low
Safety	Extremely safe
Space needed and weight	Low
Simplicity	Extremely simple
Ability to withstand shock and vibration	Rugged beyond belief

During the past few years, the deadly impact that synthetic plastic materials have on marine sea life has been graphically documented and widely publicized by environmental organizations. Countless photographs document the deadly consequences of ingestion of plastic by birds, turtles, and marine mammals, and their entanglement in synthetic fishing line and nets and in plastic sheeting.

Clearly, the Navy is not a contributor to the deadliest form of marine plastic--the synthetic rope of fishing nets. The low number of Navy ships at sea compared to the commercial fishing and merchant fleets makes the Navy a minor contributor (ca. 2.5%) to the total plastics waste problem. However, the high population density aboard naval vessels and the plastic waste discharged daily from each ship at sea adds up over time. As a role model, the Navy must demonstrate leadership with an intensive effort to eliminate the discharge of floating marine debris.

The International Convention for the Prevention of Pollution from Ships (commonly known as MARPOL) was the first comprehensive agreement to control marine pollution worldwide. The MARPOL was drafted in 1973 (MARPOL 73) and updated in 1978 (MARPOL 73/78). The MARPOL 73/78 included Annex V as an option which would prohibit ships from discharging plastic wastes at sea. The convention was ratified in 1980 with its protocol of Annexes 1 and 2 to eliminate the discharge of oil at sea; yet, it was 1987 before the international outcry against plastic waste forced leaders around the world to take action on Annex V.

In the fall of 1987, the U.S. Senate gave its unanimous consent to the ratification of Annex V to MARPOL 73/78. The 29 signatory nations represented over 50% of the world's merchant fleet tonnage. Annex V dictates that no vessel from a signatory nation may dispose of any plastics into the sea or dump floating solid waste within 25 nmi of any shoreline. Annex V also prohibits the discharge of any solid waste (except ground food waste) into special areas such as the Baltic or Mediterranean Seas.

Congress passed enabling legislation immediately after ratification of Annex V--the Marine Plastic Pollution Research and Control Act of 1987 (Public Law 100-220), which took effect 1 January 1989 for all maritime vessels, and takes effect 1 January 1994 for Navy ships. Congress recognized that full compliance in 5 years would be extremely difficult for the Navy because of the time required to complete development of and to procure and install the appropriate equipment on about 500 ships. Therefore, Congress required that the Navy report in 3 years on progress made toward full compliance, with the expectation that the compliance deadline could be extended if warranted.

In October 1987, the Assistant Secretary of the Navy for Shipbuilding and Logistics created an ad hoc advisory committee on plastics. For 7 months, the committee met and traveled to Navy research centers and supply depots, and visited several naval ships of various types. In June 1988 it delivered its final report to the Assistant Secretary. The report contained 42 specific recommendations for the Navy to meet its solid waste management goals by 1994. The recommendations were divided into four categories: technology, operations, supply, and education.

CRITICAL NAVY ISSUES

In formulating a plan to achieve full compliance with P.L. 100-220, a number of critical issues had to be addressed.

- How do we separate the plastic waste, which comprises 7% by weight of all the solid waste generated, without creating labor-intensive efforts, which could negatively affect crew morale?

- Where do we install solid waste processing equipment aboard a military vessel so that it is centrally located, efficiently arranged, and minimizes the crew's labor burden? (While the food waste (0.58 kg (1.28 lb) per person per day) can be discharged directly overboard at sea when processed through galley or scullery garbage grinders, the remaining solid waste (0.85 kg (1.87 lb) per person per day) must be transported and processed for disposal or storage. For example, 900 kg (close to 1 ton) of waste per day is generated at dozens of different rates and locations aboard a 1,000-man ship. It must be carried by hand to processing centers and then carried elsewhere for disposal or long-term storage.)

- Where do we find space to store solid waste? (There is very little designated trash storage space aboard a warship, and there are no unused spaces that can readily be made available. However, since plastic waste cannot be discharged overboard, space must be found without creating fire, health, or sanitation hazards, and without reducing the quality of life aboard ship. Full regulatory compliance demands that equipment be developed specifically to process plastic waste for volume reduction and sanitation.)

- How do we reduce the quantity of plastic waste generated aboard ship? (Alternatives are available for products such as polyethylene trash bags and polystyrene coffee cups. However, plastic is widely used for packaging, and often is the most cost-effective material for that application, especially food products. It has taken years to develop and implement plastics that are efficient and economical (e.g., shrink wrap). Material and product substitutions that perform as well and are as economical may require a long-term search.) Realistically, plastic waste may best be managed by accepting its continued use and developing a plastic waste processor which, together with recycling, will allow us to control the plastic waste storage problem aboard ship.

NAVY PLAN FOR FULL COMPLIANCE

The Navy's approach to full compliance with MARPOL Annex V and P.L. 100-220 contains four parts. They are technology initiatives, operational changes, substitutes for plastic products, and education. We may think of "people" as the fifth part of our approach. Unfortunately, the human side is sometimes the most difficult to specify, predict, and control.

Technology Initiatives

In the context of naval ships, technology refers to the equipment that will be installed to provide each ship with part of the capability required for onboard management of solid and plastic wastes. It is important to understand the rationale behind solid waste technology initiatives before the details can be presented.

First, our shipboard technology initiatives reflect the need to comply with all of the requirements of Annex V, which includes managing the total solid waste stream and prohibiting the discharge of plastics. The complexities associated with shipboard equipment installation force us to consider the total solution to the problem rather than small areas at a time. This approach seems necessary also if we are to achieve our goal and implement timely solutions at a reasonable cost. Therefore, the Navy's technology program places the same emphasis on solid waste management as on plastics discharge prohibition.

Second, a "generic" solution for a "typical" ship would be reassuring; however, many unique solutions are needed to satisfy the multiplicity of ship designs and operating scenarios. The Navy may install solid waste management equipment on approximately 500 ships that fall into about 60 different ship classes! Additionally, surface ships may carry as few as 200 people or as many as 6,000, and submarines have requirements that are entirely unique.

Third, naval ships differ significantly from commercial vessels and will find it more difficult to comply with Annex V because their population density usually is much higher. A 305-m (1,000-ft) naval ship may have a crew of 6,000, while the same size oil tanker may have a crew of 40. Obviously, the contributing population determines the quantity of plastic and other solid waste produced. While the maritime fleet has similar problems with large population densities on cruise ships, they differ significantly from Navy ships in their mission, purpose, and time at sea. Furthermore, Navy ships have no occupational specialty to manage solid waste.

The Navy is developing three shipboard systems that will be major factors in our compliance with Annex V: a vertical trash compactor, a solid waste pulper, and a plastic waste processor. Each system will be of a single size with a fixed capacity, making it easier to train operators and obtain parts necessary for repair and maintenance. Larger ships may require multiple units.

Presently, onboard incineration of solid and plastic wastes does not play a major role in the Navy's plan to comply with Annex V, because this type of burning emits potentially toxic and corrosive waste products in its exhaust gases and ash. Additionally, our experience with conventional marine solid waste incinerators has shown that suitable, high-capacity incinerators that meet the requirements of Table 2 are unavailable. However, we are investigating advanced thermal destruction technologies for limited use on ships operating under unique conditions; in some cases, this may be the best alternative to achieve ultimate, at-sea volume reduction of solid waste.

Shipboard Vertical Trash Compactor

The Navy's research and development program of trash compactors began in 1979. Our objective was to develop a machine that was reliable, easy to operate, sanitary, safe, and would allow ships to meet environmental regulations for the discharge of solid waste. We found it difficult to achieve negative buoyancy in trash that was compacted into a degradable container. Finally, we were able to ensure that the container would sink by spraying seawater into the compaction chamber, then using high compaction pressure to force the water into the pores of the trash to displace the air. A preproduction prototype, such as the one shown in Figure 1, is undergoing technical evaluation aboard a Navy destroyer and has met with outstanding success in the past year.

The Navy shipboard vertical trash compactor was designed to meet Navy standards for maintainability, reliability, safety, shock, vibration, structure-borne and airborne noise, electromagnetic compatibility, and habitability. It can process solid waste composed of glass bottles, metal cans, paper products, and other nonindustrial and nonhazardous waste into 20.4-kg (45-lb) trash slugs. The slugs are contained in cloth bags that can be hand carried. The compactor provides extended-time trash storage, trash slugs that sink without added metal weights, continuous safety checks, and fully automated operation controlled by a programmable logic controller. The most critical parts of the compactor are made from materials that are corrosion resistant; the compactor can be disassembled for movement and installation aboard ship. Its vertical configuration results in a footprint only 0.6 × 1.8 m (2 × 6 ft). Volume reductions greater than 5:1 were achieved when processing plastic waste for storage aboard ship. The first of these units should be delivered to the fleet within 2 years.

Shipboard Solid Waste Pulper

Pulping solid waste is not new to the Navy. One class of ship has been successful in using commercial pulpers to process mixed solid waste. Galley and scullery food waste disposers are actually small pulpers. Used as a shipboard solid waste processing method, pulping mixes waste with water, reduces the size of the solids, and creates a wet pulp or slurry, which can be pumped directly overboard. Pulped waste is more readily biodegradable than unpulped waste, tends to be negatively or neutrally buoyant, and disperses rapidly when discharged.

Typically, pulpers operate as follows. Waste enters a large tank through a feed chute and is mixed with water. The water softens and saturates the waste material so that it can be reduced in size more easily. The mixture forms a vortex caused by the rotation of a cutting mechanism located in the bottom of the tank. The pumping action of the cutting mechanism draws trash down the vortex to the bottom of the tank where it is cut and pressed through a perforated sizing ring before being discharged as a slurry. The Navy shipboard pulper is being designed to process paper, food waste, and fiberboard. A conceptual design of the pulper appears as Figure 2. Metal, glass, plastic, and cloth are considered nonpulpable, although the design of the pulper makes it highly resistant to damage from accidental insertion of these items. It will process about 75% of the total solid waste generated aboard a ship at a rate of 262 kg (600 lb) of mixed solid waste per hour. Our experience demonstrates that these pulpers are extremely reliable and simple to operate. The first units could be delivered to the fleet within 4 years.

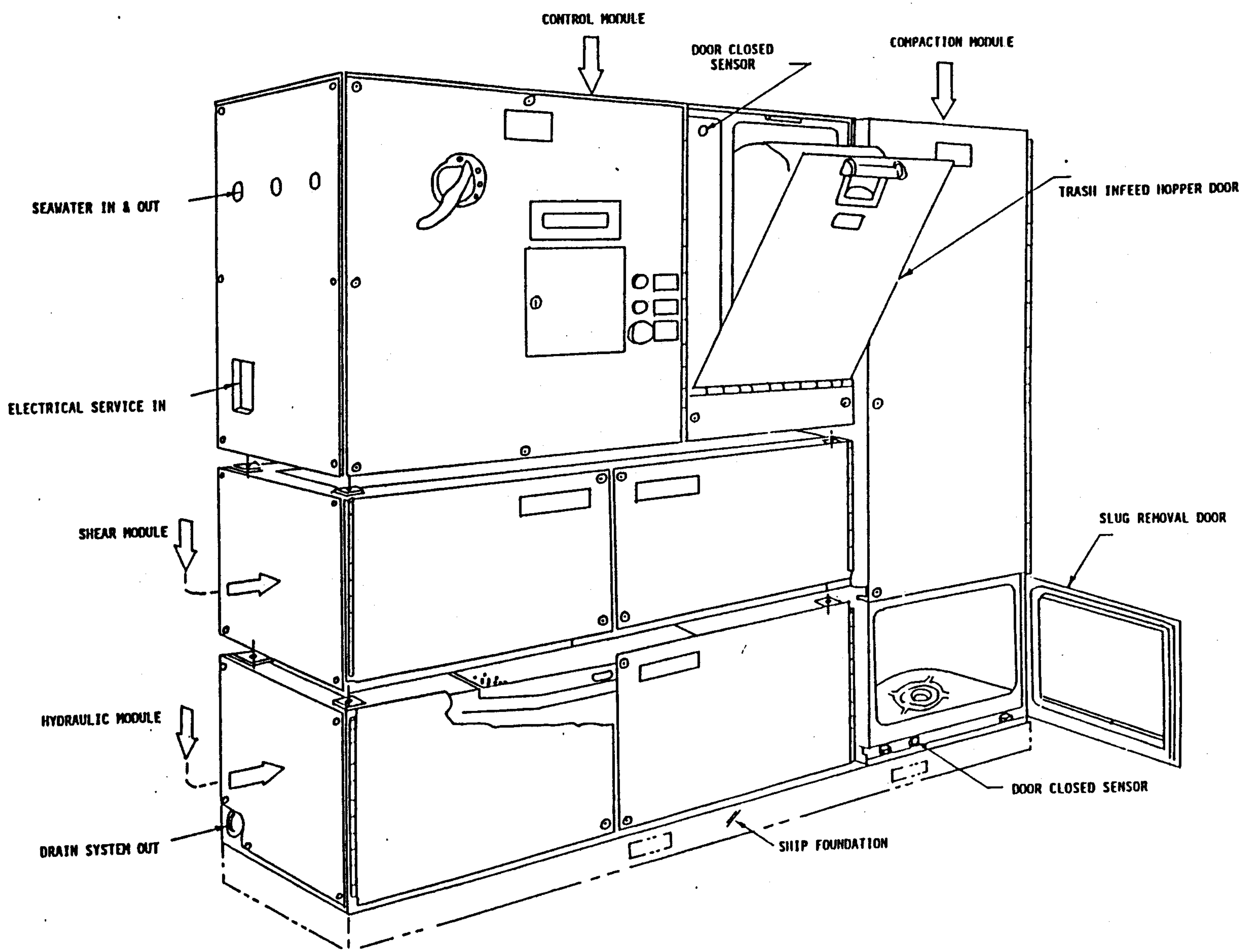

Figure 1.--Shipboard vertical trash compactor.

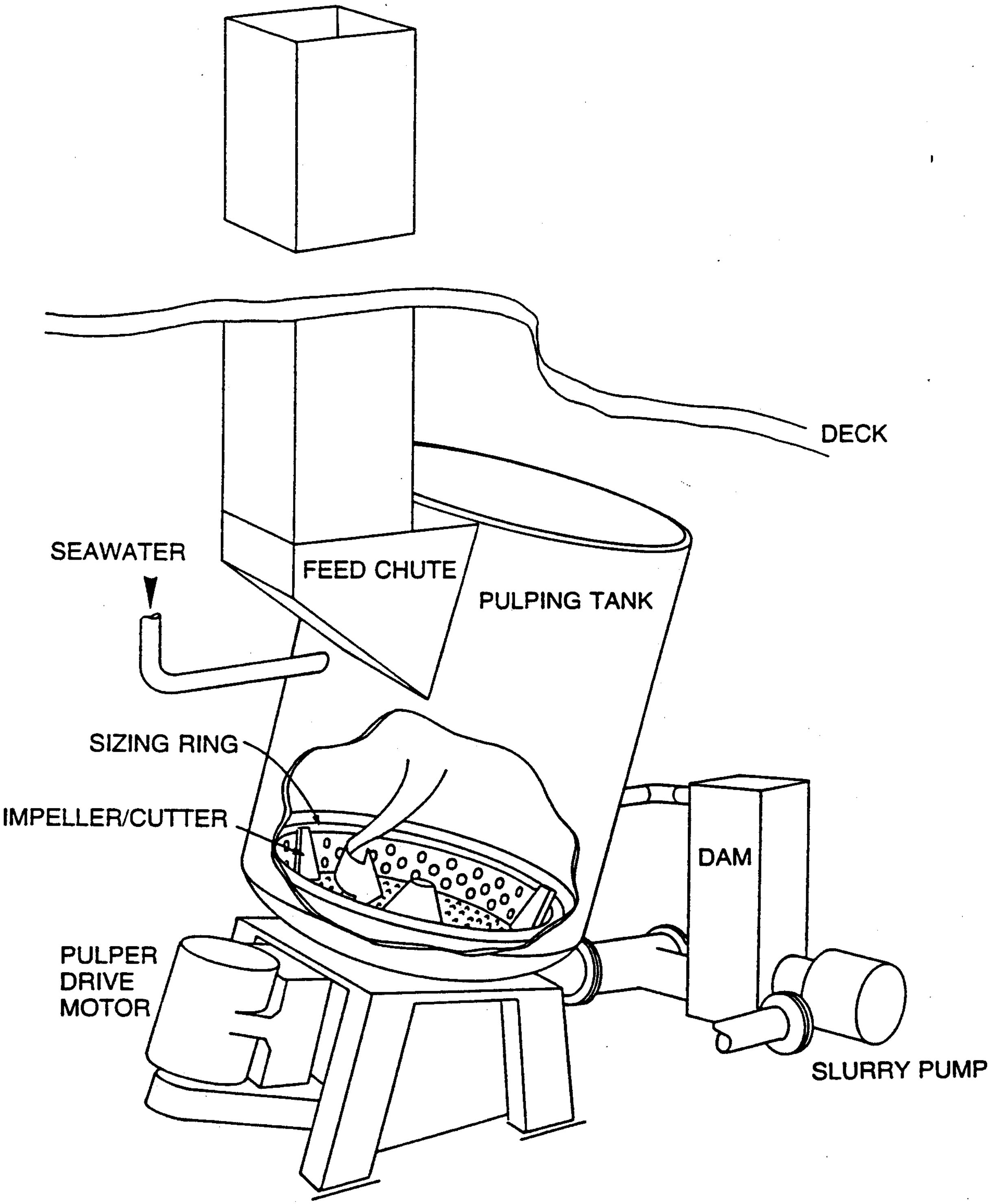

Figure 2.--Shipboard solid waste pulper.

Plastic Waste Processor

Plastic waste comprises about 7% by weight of the total solid waste generated on board a Navy ship. Of that quantity, 50% is contaminated with food waste. Storage of food-contaminated waste aboard ship requires significant volume reductions along with sterilization or similar treatment to control noxious odors.

The Navy's shipboard plastic waste processor is in the early stage of development. While the exact design and configuration are uncertain, Figure 3 depicts our developmental objective. The densified, sanitized block of waste plastic will be suitable for long-term shipboard storage until it can be off-loaded ashore. We anticipate a 30:1 volume reduction and an end product that is recyclable. Our goal is to have the first units delivered to the fleet within 6 years.

Shipboard Equipment Configurations

To plan the installation of our solid waste management equipment, naval ships are grouped into four categories--small, medium, and large surface ships, and submarines. The conceptual plan calls for compactors only to be installed on small surface ships; compactors and plastic waste processors on the mid-sized ships; and compactors, plastic waste processors, and pulpers on larger ships. Some larger ships may require more than one of each system to ensure maximum efficiency. This plan assumes that personnel on board each ship will separate plastic manually at its source and will use their food waste disposers.

On smaller surface ships, all solid waste (except food) will be processed through the compactor. Negatively buoyant, nonplastic slugs will be stored on board for shore disposal or for overboard discharge where permissible. The compactor can process an all-plastic slug which provides at least a 5:1 volume reduction.

Medium-sized surface ships can accommodate a compactor and a plastic waste processor. The compactor will process all of the solid waste except separated plastics and food waste. Nonplastic slugs will be stored on board for disposal ashore or for overboard discharge. The plastic waste processor will process all plastics including food-contaminated waste, and the densified (30:1) and sanitized plastic will be stored on board for disposal ashore.

All three systems will be installed on larger surface ships in single or multiple units, depending on the need and the space available. Each system will be targeted to a specific segment of the solid waste stream to ensure maximum utilization and efficiency. Separated plastic waste will be processed for storage and shore disposal. The remainder of the solid waste stream will be separated at its source into pulpables (e.g., paper, fiberboard, and light wood) and nonpulpables (e.g., glass and metal cans). The compactor will process nonpulpables into negatively buoyant slugs for overboard discharge when the ship is 25 nmi from the shoreline. Pulpables will be processed by the pulper when the ship is at least 12 nmi from shore

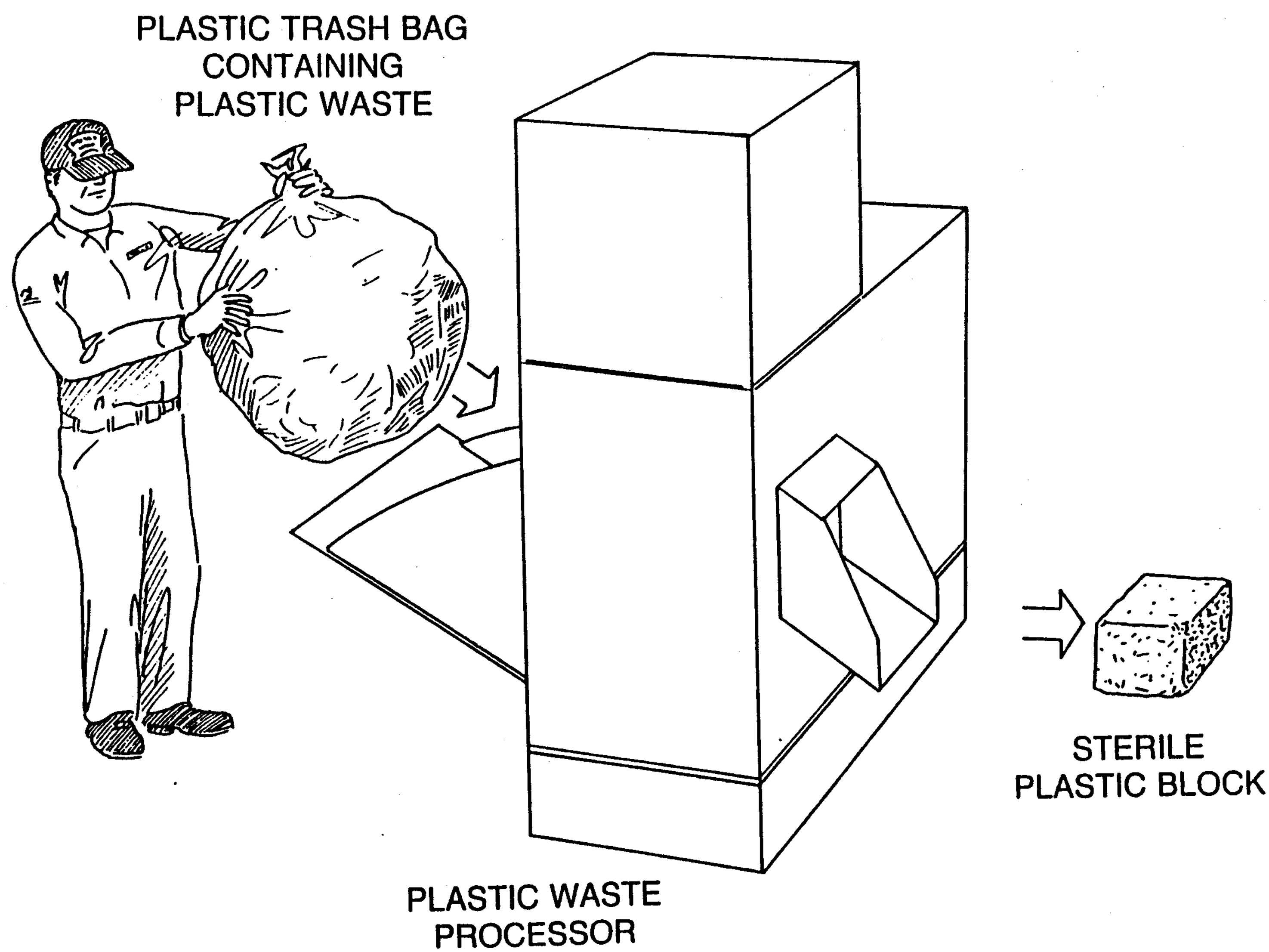

Figure 3.--Shipboard plastic waste processor.

and pumped overboard. Larger ships are most able to maximize the use of waste management technology and minimize the amount of waste retained on board for shore disposal.

Because of limited space and other constraints, the current Navy plan does not include the development and installation of new solid and plastic waste equipment for submarines. However, submarines will comply with Annex V to the maximum extent possible by using material substitutions to minimize the generation of plastic waste; by source separation and onboard storage of plastic waste that is not food-contaminated; and by continuing the current practice of compaction, weighting for negative buoyancy, and overboard discharge of the remaining solid waste.

Operational Constraints

The Navy's response to the need for operational changes met with four major constraints.

1. *Manpower.*--An 81-h work week is standard for sailors operating at sea, and expectations of what a crew member is to accomplish during a shift leaves no time for special handling of plastic waste. The establishment of additional jobs to fulfill this need is not probable because no funding is available for such a position, and there is no berthing space on the ships for additional crew members.

2. *Space.*--Space is at a premium aboard even the largest naval ships. The typical seagoing merchant ship is considerably larger than the average naval surface combatant, yet its crew numbers 30 compared to 300 sailors aboard a Navy ship. While aircraft carriers are the largest ships in the fleet, their crew exceeds 6,000, thus making their population density similar to that of our smaller surface ships. The cramped quarters aboard our ships leave little space for the installation of new equipment.

3. *Quality of life.*--It is critical that the Navy maintain the quality of life at sea as a top priority to enable us to continue to attract high quality personnel. Routine operations involve 7 to 25 continuous days at sea, with 45 days not unusual. Long deployments may require 80 to 150 continuous days at sea. Thus, it is imperative that each sailor have a clean, healthy, and safe place in which to live. Controlling plastic waste cannot be allowed to negatively affect quality of life aboard ship.

4. *Financial constraints.*--Congress has not allocated additional funds for the increased operating costs that will be incurred during implementation of the procedures to prevent plastic pollution. In fact, budgets are being cut and daily operating funds are scarce. In forecasting the operational changes ahead, funding concerns force us to note that the

cost of paper coffee cups is double that of polystyrene cups, and paper trash can liners are quadruple the price of those made of plastic.

Hence, the Navy must reduce plastic pollution in the marine environment while operating within these realities. We must change the way we process solid waste, yet minimize the increase in manpower and financial resources required and maintain the high quality of life aboard ship.

Substitutes for Plastic Products

Many items contribute to the problems of plastic waste aboard ship, most of which cannot be controlled. A destroyer with a crew of approximately 300 was used as one of our plastic waste reduction demonstration study ships. During one 16-day period, the David Taylor Research Center study team inventoried 6,179 individual pieces of plastic waste. "Miscellaneous" sources, those not attributable to berthing, work center, or food service areas, accounted for 25% of the waste. The two most numerous items were six-pack rings and trash bags; however, frozen meat packaging, food wrap, and food containers accounted for 14 of the remaining top 23 categories of plastic waste collected. Acceptable, nonplastic substitutes for these items will not be available for many years, if ever.

However, nonplastic substitutes are available for some of the plastic items. Ships have found nonplastic substitutes for coffee cups and stirrers, tableware, and trash can liners. While plastic bags are still used to collect and hold plastic waste for disposal ashore, paper bags are now specified for collection and at-sea disposal of nonplastic solid waste.

New procedures will eliminate some disposable plastic products. For example, food waste can be disposed in food pulpers or garbage grinders, which eliminates serious storage problems caused by the collection of food waste in plastic bags. This practice also requires less manpower; the daily garbage does not have to be carried from the galley to the fantail and dumped overboard for disposal.

Education

All shipboard personnel must be educated on the hazard that waste plastic poses to marine life and on the procedures necessary for effective shipboard solid waste management. Navy personnel have become increasingly aware of the potential adverse impact that shipboard operations have on the environment. Shipboard solid waste separation management must become a task that each crew member accepts as part of the ship's routine operation.

IMMEDIATE REDUCTIONS IN PLASTICS DISPOSAL AT SEA: SHIPBOARD PLASTIC WASTE REDUCTION DEMONSTRATIONS

The 5-year implementation period does not afford us the time to conduct paper studies. While the research and development required for technical solutions have been accelerated and are moving forward as quickly as possible, we must implement changes in waste management and disposal practices now, not because Congress expects it of us, but because it is environmentally expedient.

Changing shipboard operational procedures was the single viable alternative to effect the expeditious reduction of plastic wastes discharged at sea. Our focus was on the segregation of plastic wastes from other solid wastes, and its short-term storage aboard ship. Many of the recommendations in the report of the ad hoc advisory committee on plastics were directed toward achieving this objective. Shipboard plastic waste reduction demonstration studies were conducted aboard five surface ships and two submarines to test and evaluate each recommendation. Studies on two additional surface ships are planned. Thus far, the demonstration studies have illustrated several major points:

- Navy shipboard plastic waste represents about 7% by weight of the total solid waste stream; 50% of that waste originates in food service areas.

- Plastic waste generation is nearly constant across ship classes, ranging between 45 and 90 g (0.1 and 0.2 lb) per person per day.

- Separation of the plastic from other waste at its source was most effective and required the least effort. Trash cans or bags labeled "Plastic Waste Only" were essential. In most living and work spaces they would hold a 1- to 2-week accumulation of plastic waste.

- Onboard storage of plastic contaminated with food waste was limited to approximately 3 days before the noxious odor began to affect the quality of life and it posed a threat to health and sanitation conditions.

- Uncontaminated plastic waste can be stored on board up to 3 weeks; the originating work center seems to be the most appropriate choice for storage on most ships. The plastic waste was collected and placed in pier-side dumpsters when a ship returned to port.

POLICY GUIDANCE

The commanders of the Atlantic and Pacific fleets have issued policy guidance to the commanding officers of the ships. Each ship must separate and store plastic that is not contaminated with food waste for at least the first 20 days of any underway period, and longer if space allows. Plastic that is contaminated wth food waste must be held on board for the last 3 days of any underway period. Plastic waste stored on board will be off-loaded in port. If retention compromises the health, safety, or combat readiness of the ship and those aboard, properly packaged and negatively buoyant plastic waste may be discharged overboard when the ship is beyond 50 nmi from any shoreline. Such disposal must be approved by the commanding officer and a log entry made indicating the time and position of overboard discharge. Noncompliance with the dumping policy must be reported in writing. This policy became effective 15 January 1989 for ships in the Atlantic fleet, and 1 March 1989 for Pacific fleet ships. The effective dates were chosen to coincide with the issuance of education packages for each ship. Each package includes the "Ship's Guide for the Management of Plastic Waste at Sea."

Fleet implementation of the new procedures will produce an immediate reduction in the total plastic waste discharged overboard by an astounding 70%! The aggressive action exhibited by our operational forces affords our engineering community time to develop and install solid waste management equipment aboard ships that will promote still further reductions. Also, the Navy's supply community will use this opportunity to research alternative products to reduce the amount of plastic used on board ship. The U.S. Navy stands firmly committed to achieving full compliance with all environmental regulations.

SHIPBOARD WASTE DISPOSAL: TAKING OUT THE TRASH UNDER THE NEW RULES

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ABSTRACT

In 1988, the Society of Naval Architects and Marine Engineers Panel M-17, Disposal of Shipboard Wastes, convened two workshops to encourage open discussion of the diverse options available to comply with MARPOL 73/78 Annex V (Garbage). This paper reviews the available engineering, operational, and managerial changes useful in implementing Annex V and outlines the "good marine practice" suggested by the discussions in Panel M-17. Examples of approaches actually adopted by different commercial operators will be offered.

INTRODUCTION

A new marine pollution prevention regime, MARPOL 73/78 Annex V (Garbage), came into force internationally on 31 December 1988 (International Maritime Organization (IMO) 1978; U.S. Congress 1987). Annex V requires ship operators to change the way shipboard garbage is handled and immediately bans discarding plastic materials anywhere in the sea (Whitehead 1988). Disposing of shipboard garbage properly matters more to the company, the sailor, and the national authorities, because Annex V changes the long-accepted maritime practice of tossing garbage into the sea. However, taking out the trash under the new rules means more than stopping sailors from chucking everything over the side. Annex V is no antilitter campaign, but is part of a fundamental shift in the way ship crews and managers operate (Horsman 1982; Vauk and Schrey 1987). Making the transition to a commercial fleet that is able to obey the MARPOL Annex V will take a combination of changing how people have usually done things and providing them with the tools they need to do things differently.

Implementing Annex V has become the job of ship designers, ship operators, and maritime environmental specialists who have the expertise in shipboard systems design and operation. A ship is a small place, of a fixed size, occupied by people, cargo, and a lot of machinery. Rarely is a ship built with spare space or operated with extra people. Under these common constraints, a change in one shipboard activity often has a consequence in another activity. In this paper, the author examines the implementation of the MARPOL Annex V in the merchant fleet from the

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

perspective of the marine technical professionals, to convey a sense of the "good marine practice" they need to select, install, and operate solutions to comply with Annex V.

Background: The Role of the Society of Naval Architects and Marine Engineers

The Society of Naval Architects and Marine Engineers (SNAME) is a U.S. organization of ship designers, ship builders, and ship operators. One standing technical panel of the society is Panel M-17 (Disposal of Shipboard Wastes), which is made up of professionals who work in engineering and management to enable ships to meet the legal requirements for environmental protection (SNAME 1982). In 1988, the SNAME Panel on Disposal of Shipboard Wastes convened two shirt-sleeves workshops on "The Shipboard Engineering and Environmental Aspects of Implementing MARPOL 73/78 Annex V (Garbage)" to encourage open discussion of the diverse options available to comply with Annex V. The first panel workshop on 18 July 1988 was hosted by the Office of the Chief Scientist, National Oceanic and Atmospheric Administration (NOAA). By popular demand, a second meeting was held on 12 October 1988, hosted by the Waste Combustion Equipment Council of the National Solid Waste Management Association (NSWMA).

The Panel M-17 workshops have been lively and useful exchanges of information and opinion. More than 80 people attended, including waste disposal firms representatives, port authority representatives, fleet operators, marine engineers and designers, environmental lawyers and regulators, and supply officers, all of whom have work to do to implement Annex V. The meeting participants provided useful information about shipboard and shoreside waste disposal equipment, local port implementation needs, disposal costs, U.S. Coast Guard regulatory proposals, and ways to design a compliance alternative that make sense for individual ships (Martinez 1989).

Enlightened self-interest helped motivate such a free exchange of information. Each fleet had to comply with the new international convention by 31 December 1988, with little lead time to order equipment or change vessel operations. Domestically, the Coast Guard had only a year after Congress passed the new law to draft and issue new rules that apply to all boats, ships, and oil rigs operating in the waters of the United States. No regulations were in place and many in the merchant marine were uncertain what would satisfy the authorities or how to do it. It seemed a good idea to sit down and talk about what we faced.

Background: MARPOL Implementation Philosophies

The MARPOL 73/78 Annex V (Garbage) is the third pollution prevention regime to be imposed on the world merchant fleet. Official shorthand for the International Convention for the Prevention of Pollution from Ships 1973, as amended by the Protocol of 1978, the MARPOL 73/78 contains five annexes that address particular types of ship-source marine pollution. The first annex implemented addressed oil pollution and the second addressed chemical cargo wastes. However, Annex V is philosophically different in its approach, and maritime professionals need to understand that philosophical difference.

The MARPOL 73/78 Annex I (Oil) and Annex II (Bulk Chemicals) prescribed the way to comply, including which equipment to use and what procedures to adopt. In addition, it was clear where the responsibility for day-to-day compliance rested. The wastes involved come from cargo tanks, which are the responsibility of the deck officers, or from machinery spaces, which are the responsibility of the engineers. Enforcement and compliance were rigidly defined, and neither the Coast Guard nor ship operators had much leeway from the very start. Finally, not all vessels had to comply by the same date, because internationally agreed upon schedules gave older vessels more time to come into compliance.

The MARPOL 73/78 Annex V (Garbage) is so different that it has taken a while to get used to it. Annex V mandates that overboard disposal must change and that plastic disposal must cease, but implementing Annex V relies on none of the methods which were so central to the previous pollution conventions. Annex V instead:

- applies to ship-generated garbage, regardless of the source, and clearly includes hotel and galley services, which are the responsibility of the stewards;

- does not require specific new equipment in either ships or ports;

- does not tell ship operators or port authorities how to comply; and

- applies to all vessels in all waters immediately, with no delayed implementation schedules for existing vessels.

These are both the strengths and the weaknesses of the entry into force of Annex V. On the positive side, operators are not shackled to a technologically rigid solution and are free to develop their own best way to comply with the new requirements. Also on the positive side, implementing Annex V is not just the engineer's or deck officer's responsibility, but is a shared responsibility across the ship's crew and the shoreside supporting organization. This allows an operator to experiment and make incremental changes that can yield a compliance solution tailored to the way the ship operates (U.S. Department of Commerce 1988). On the negative side, the entire fleet had to comply by 31 December 1988, which meant that few people had the experience in solving the problem aboard ships and few were familiar enough with the annex to protect themselves from the uninformed speculation that was circulating, and everyone wanted equipment or advice at the same time.

TACKLING THE PROBLEM

Table 1, the "MARPOL 73/78 Annex V Summary of Garbage Discharge Restrictions," (U.S. Department of Transportation 1988b, 1988c) sets out

Table 1.--The MARPOL 73/78 Annex V summary of garbage disposal restrictions.

Garbage type	All vessels except offshore platforms and associated vessels		Offshore platforms and associated vessels[b]
	Outside special areas	In special areas[a]	
Plastics--includes synthetic ropes and fishing nets and plastic bags	Disposal prohibited	Disposal prohibited	Disposal prohibited.
Floating dunnage, lining and packing materials	Disposal prohibited 25 nmi from nearest land	Disposal prohibited	Disposal prohibited.
Paper, rags, glass, metal, bottles, crockery, and similar refuse[c]	Disposal prohibited <25 nmi from nearest land	Disposal prohibited	Disposal prohibited.
Food waste not comminuted or ground	Disposal prohibited <12 nmi from nearest land	Disposal prohibited	Disposal prohibited.
Food waste comminuted or ground[c]	Disposal prohibited <3 nmi from nearest land	Disposal prohibited <12 nmi from nearest land	Disposal prohibited <12 nmi from nearest land.
Mixed refuse types	(d)	(d)	(d)

[a]Special areas are the Mediterranean, Baltic, Red and Black Seas, and Persian Gulf areas.

[b]Offshore platforms and associated vessels includes all fixed or floating platforms engaged in exploration or exploitation and associated offshore processing of seabed mineral resources, and all vessels alongside or within 500 m of such platforms.

[c]Comminuted or ground garbage must be able to pass through a screen with a mesh size no larger than 25 mm.

[d]When garbage is mixed with other harmful substances having different disposal or discharge requirements, the more stringent disposal requirements shall apply.

the different classes of wastes that are now regulated and where their disposal is now restricted. As stated previously, the saving grace of Annex V is that no technology is mandated. This injects a little breathing room into the transition and removes any cause for alarm if you cannot retrofit equipment by the entry-into-force date. The open "philosophy" for compliance gives a company more freedom to design its own "right" way, but also compels a designer to consider more alternatives. It means that the role of the marine engineer in implementing Annex V is different. A company cannot delegate the task to an engineer, as was done with Annexes I and II, and expect everything to fall into place neatly. It's not that the engineer cannot deliver a technical solution, it is rather that the solution is not in the hardware.

Diverse ways are available to comply with Annex V, exercising both managerial and technical prerogative. "Management" changes can greatly reduce the amount of waste generated and reduce the size of the "engineering" solution needed. Some options affect vessel operations that are not the usual jurisdiction of the marine engineers, such as provisioning the accommodations and securing the cargo. A good starting point for evaluating the situation is to read the Marine Environment Protection Committee (MEPC) Guidelines for the Implementation of Annex V (Garbage) (IMO 1988b). This document has been written to introduce the merchant mariner and the maritime designers to the problem-solving method that is best used in handling shipboard wastes. It works well, and the credit goes to the drafters of the document for producing a practical and usable text. The guidelines are well regarded by the designers and operators who have had the opportunity to use them. Better yet, the guidelines are amenable to modifications as operators and authorities gain experience in implementing Annex V.

In the United States, marine engineers and designers have had only partial information available for fulfilling the marine engineering tasks related to Annex V. Each compliance decision has consequences for the way the ship operates, and some apparently simple solutions affect shipboard operations and costs more severely than do some apparently more complex solutions.

Shipboard sanitation and safety must be safeguarded when selecting an installation or retrofit (Signorino 1988). Panel M-17 convened to become familiar with the solid waste management practices in port facilities and with the state of the art of types of equipment used to process or destroy the wastes now addressed in the Annex V (Garbage) requirements. Very few of us, even in the Panel M-17 community of specialists, had previously studied the ship's garbage, Annex V, garbage equipment available for shipboard or shoreside use, or how to safely retrofit garbage equipment on existing ships. Some options use expensive and unfamiliar equipment, such as package incinerators, large capacity compactors, or pulpers. A quick review of the decision and technical options follows.

Estimating the Waste Stream

Before the problem can be solved, some estimate has to be devised of how much garbage will be handled. If possible, detailed inventories can be done, but many operators are unable to spend the time and money on gathering such information before compliance is required. The discussion in the M-17 meeting reviewed the various ways that people have selected to estimate the ship-generated garbage needing treatment. The following ways have been used with some success:

- The Coast Guard regulatory docket for the implementation of the MARPOL Annex V includes a study that creates a unit called the GBE or "40-gallon garbage bag equivalent" (U.S. Department of Transportation 1988a).

- The U.S. Navy 1988 inventory of shipboard waste yielded numbers of 1.4 kg(3 lb)/person/day of garbage which includes 0.5 kg (1 lb) of food waste and 0.9 kg (0.2 lb) of plastic. This is a twentyfold increase in the average amount of plastic since the 1971 inventory.

- The waste disposal industry categorizes "incinerable waste" according to its heat release by the following classification (Norske Hydro 1988). Note that these categories presume no presorting of waste (Table 2).

Characterizing the Waste Stream

Along the way, the types of shipboard activities that generate the plastic waste will be identified. Each solution to Annex V is simplified if the shipboard waste streams are kept separate, rather than being mixed. Clean plastic can be kept separate from the food-contaminated plastics and both can be collected separately from the other waste that can still be discharged at sea. But making waste separation work requires some cooperation from the crew members or passengers on the ship. It was suggested that SNAME help develop some simple crew and officer training sessions on waste source separation, to motivate and inform people about how it simplified the overall Annex V solution.

The Zero Equipment Option

Having evaluated the amounts, sources, and types of plastic being used and discarded as a result of shipboard operations, the ship operator can implement a few shipboard and shoreside managerial options to comply with Annex V. Those actions require no equipment installations, but affect shoreside company practices and shipboard crew practices.

Change the Purchasing of Ship Supplies

A quick scan of most ships identifies where plastics and other problem materials are used (Cavaliere 1988). In a number of uses, plastic has become the material of choice because it is safer to work with and is unbreakable. Other uses aboard ship, however, are convenience uses, just as are the uses of plastic ashore. It is similar to converting a shoreside business or home away from using the plastics that are so easily available.

Table 2.--Incinerable waste categorized according to its heat release.

Type	Classification of solid combustible waste materials	KJ/kg	Incombustible solids %	Moisture content %	Kg/dm^3
0	TRASH, a mixture of highly combustible waste--paper, cardboard cartons, wood boxes, and combustible floor sweepings from commercial and industrial activities. Contains up to 10% by weight of plastic bags, coated paper, treated corrugated cardboard, oily rags, and plastic or rubber scraps.	20,000	5	10	0.15-0.2
1	RUBBISH, a mixture of combustible waste--paper, cardboard cartons, wood scrap, foliage, and combustible floor sweepings from commercial and industrial activities. Contains up to 20% by weight of restaurant or cafeteria waste, but little or no treated papers, plastic, or rubber wastes.	15,000	10	25	0.15-0.2
2	REFUSE, an approximately even mixture of rubbish and garbage by weight, common to apartment and residential occupancy.	10,000	7	50	0.2-0.3

When a plastic item loses its disposable advantage, it loses most of its purchase appeal. Sometimes, an item that is currently purchased can be done without. A plastic item can be purchased in another material, a disposable item can be eliminated in favor of buying a reusable version that needs to be washed. A formal inventory may not be needed as much as a scavenger hunt for the unnoticed plastics that then become candidates for elimination.

Establish Who Is Responsible Aboard the Ship

Every cause needs a champion. In the U.S. merchant marine, jobs are commonly defined rigidly as deck, engine, or steward. Tackling Annex V implementation falls in no single department and requires the participation of all personnel or passengers aboard. Each ship should designate a specific person to be responsible for shepherding the entire ship into compliance with Annex V.

Port Reception Facilities

Send It Ashore, But Where?

Each port must provide reception facilities for shipboard garbage. If Annex V creates uncertainties for ship operators, the port operators are just as uncertain about what to do. In the past, it has been difficult and expensive for some ports to provide the reception facilities required by the previous MARPOL annexes, so ports are not thrilled by the obligation to provide "adequate" garbage reception facilities. The task is difficult for the port, which can only guess at (1) the number of ships bringing in foreign "food wastes" that will need Animal and Plant Health Inspection Service (APHIS) certified disposal, and (2) the amount of plastic-contaminated waste that will now be brought ashore to add to the port community's shoreside waste stream.

Many port cities are already straining to deal with their own municipal garbage problems, and adding more ship-generated garbage to the local landfill is not an easy thing to sell. The sentiment of those attending the M-17 meetings seemed to be that most U.S. ports are unprepared to meet the reception facility requirement and the ship operator will still be left "holding the bag."

Some German ports have already imposed a vessel fee, whether the vessel uses the port garbage service or not. At least one U.S. port is considering the same action (Nightingale 1988). Such a fee would be about $150 or more per ship per port call. Such mandatory fees affect the ship operators on those routes, because they may lessen the incentive to install extensive garbage handling equipment on board the ship.

When contracting for disposal services, the usual measurements are tons or cubic yards, because that is how the hauler is charged at the landfill (NSWMA 1988).

Animal and Plant Health Inspection Service Requirements

The port reception facilities must include APHIS waste-handling facilities. The APHIS restrictions are intended to prevent the introduction of foreign plagues, such as foot-and-mouth disease, into the United States (U.S. Department of Agriculture undated). Any organic wastes that have possibly been contaminated by contact with foreign foodstuffs or foreign livestock are subject to quarantine and can be handled only by authorized APHIS contractors or APHIS personnel themselves. The wastes taken off the ship must be totally sterilized, either through autoclaving or by incineration, and the remaining matter must be securely landfilled. The APHIS requirements are not new and are not changed by the Annex V regulations. Much of the plastic wastes coming from ships as a result of the Annex V regime, however, will be food packaging or food serving articles and is subject to the APHIS restrictions. That volume of waste may increase greatly, especially in the interim compliance periods, when vessel operators may prefer to store rather than treat the plastic wastes.

All APHIS wastes must be stored separated from other garbage to avoid contamination, and when off-loaded, it must be delivered to a certified facility for proper sterilization or incineration. All transport must meet strict quarantine requirements. As a result, APHIS waste is expensive to handle. A ship may be billed by the pound of APHIS waste handled per pick up and frequency of pick up, since transport to an APHIS-certified facility is regulated. Ship officers and crew should make all efforts to keep the APHIS waste separated from regular garbage that does not require quarantine. Otherwise, the APHIS inspector, who makes the final decision as to which wastes must be quarantined, may require much larger amounts of ship's garbage to be quarantined, at the expense of the ship operator. The APHIS wastes should be stored on board the ship in leakproof containers until removal. There is no approved container, and it was the opinion of the waste handlers at the meeting that a Rubbermaid Roughneck, such as is used for curbside garbage pickup, was probably sufficient.

There are currently no more than 43 APHIS facilities in the area of U.S. ports. Wastes may not be transported through rural areas, which makes reaching some remote marine terminals almost impossible. Ship operators should contact their local APHIS officers immediately to get the details about any existing or planned APHIS-certified facilities in the vicinity of the ports where they anticipate needing APHIS wastes handled. It was also suggested that operators inquire of their shipping agents or ship management agents what kind of services the agents can provide.

Recently, APHIS administrators have brought up a new concern about handling compacted wastes. The APHIS regulations for steam sterilizing foreign garbage are based on experience with handling fresh, uncompacted wastes such as are off-loaded from an international airline flight. The autoclaving procedures depend on killing temperatures penetrating the core of the mass of garbage, and a half hour has generally proved effective with a margin of safety. However, well-compacted wastes are, by definition, more dense, and the APHIS has no confidence that a half hour of steam exposure will penetrate the core of the garbage mass. Practically, this means that a ship operator should now be cautious about compacting APHIS wastes as well, because the savings in storage may be offset by a higher cost for APHIS disposal. The APHIS is likely to have to recalibrate the autoclaving time to compensate for the degree of compaction of the wastes (i.e., 10 to 1, 20 to 1, 40 to 1) in order to ensure that the steam penetrates to the core and kills. Any longer interval of autoclaving is certainly going to increase the operating costs of the autoclave and the price of APHIS disposal for the compacted wastes.

The APHIS-quarantined wastes are not the same as "infectious" wastes. It is important not to confuse the two, because it is much more expensive to dispose of infectious wastes (i.e., hospital wastes). Plus, there is so much public outcry over the recent well-publicized incidents of hospital waste washing ashore on eastern U.S. beaches that no ship operator should invite trouble by using the term "infectious waste" when he means APHIS-quarantined waste.

The Shipboard Equipment Option

Though Annex V requires no equipment to be installed on a ship, many operators will choose to add garbage handling equipment such as compactors, comminuters, or incinerators. Each piece of equipment installed, whether new or retrofit, needs to operate safely and effectively and not create any disease hazards for the shipboard personnel. In all cases, the tradeoffs need to be identified before expensive decisions are made. In the MEPC Guidelines, Section 5, "Shipboard Equipment for Processing Garbage" requests ". . .information on the development and use of shipboard. . ." comminuters, compactors, and marine garbage incinerators. This is a genuine request for a technical exchange and is another of the provisions unique to Annex V implementation.

Comminuters: Specifications and Installation Needs

Comminuters are a type of heavy-duty garbage grinder. Though not required by Annex V, comminuters are mentioned in both Annex V and in the proposed U.S. regulations. They are useful primarily for handling galley and scullery wastes that can be discharged in the zone between 3 and 12 nmi offshore (or anywhere within a special area). Comminuters must reduce the wastes to pass through a screen 25-mm (1-in) square. Such equipment is available for galley installation and works well.

Storage tanks for comminuted food wastes were discussed briefly. Such a tank allows a ship's steward to continue comminuting food wastes while within 3 nmi, but avoid discharging it into restricted waters. If used, the tanks must be installed so as to be easily flushed clean. Tank materials must be able to withstand potential corrosion from rotting food slurries and must be adequately vented to prevent anaerobic conditions in the tank.

Comminuted food wastes should never be flushed to black water (sewage) holding tanks or to marine sanitation devices (shipboard sewage treatment plants). Food wastes cannot be adequately degraded by the microorganisms in the systems and can overload the aerobic capacity of the tanks and make the whole system go septic. Such a ghastly mess must be avoided at all costs.

Pulpers

The SOMAT Corporation makes a pulper for use on U.S. Navy ships that works like a comminuter, but further processes the slurried waste to press out the water and dry the waste material enough to make it easier to burn or store. One unit can separate out plastics because the plastics float in the pulping chamber while the other wastes pass through. These devices are about the size of a washing machine.

Compactors: Specifications and Installation Needs

Garbage compactors, used on some ships, have had mixed success. Many of the original units were never intended to be installed on a rolling, heaving ship or be used in the salt-laden sea atmosphere. Purpose-built units for marine installation are now readily available, however, and they fare better. The principal reason for using a compactor is clear: garbage storage takes less room. However, the stored compacted garbage, especially food-contaminated plastics, can "ripen" to a stinky mess if not properly isolated and disinfected. The M-17 discussion raised the following points:

- Hygiene for stored wastes needs to be guaranteed, since the accumulated wastes will otherwise rot and attract vermin. The U.S. Public Health Service (PHS) has standards for shipboard sanitation that must not be compromised. To prevent rotting, food wastes may need to be frozen or at least refrigerated in the 40°F cold room until disposal ashore. This may cut into the steward's storage space.

- Though compactors are usually not large, using them requires organizing the garbage collection and installing them requires identifying enough space for storing the compacted garbage as well. Both the compactor space and the storage space should have adequate space drains and hose washdown fixtures. The discharge of the "compactor juice" created is not regulated, as far as anyone present knew.

- Compactors may be used with unsorted garbage or with separated waste streams. It may be worthwhile for a ship to install more than one compactor, if one is used principally for the APHIS wastes generated from the galley and the other is used for all other plastic-containing wastes generated on board the ship that do not need quarantine. One fleet operator suggested that compactors were also useful for baling dry wastes to be recycled.

Incinerators: Specification, Selection, and Use

Using an incinerator for plastic wastes enables the ship crew to destroy the troublesome wastes rather than hold them and rely exclusively on port reception facilities or shoreside waste haulers. Ship operators consider incinerators in a tradeoff study against other compliance options in the implementation of the MARPOL Annex V. The Annex V rules require only compliance, and the ship operator will want to know as much as possible about the consequences of installing an incinerator before making the decision.

Incinerators available for shipboard use differ significantly from each other and cannot be considered all the same. They differ in number of combustion chambers, rate of waste feed, form of waste feed, auxiliary fuel required, pretreatment or waste separation needed, amount of operator training needed, auxiliary equipment or ventilation needed, retrofit installation difficulties, and other ship-specific parameters.

Before installing an incinerator, a ship operator must know what needs to be incinerated and in what amounts. Some wastes require shredding or similar pretreatment before incineration. Other wastes require more fuel to destroy than makes sense, so those wastes (e.g., metal scraps) should be separated ahead of time. Some wastes (e.g., glass) cannot be incinerated in some incinerators, but are handled by others. No single size vessel "needs" an incinerator. Ship owners are going to make this type of decision based more on how many people are on the ship and how the ship operates.

There are no technical standards for shipboard incinerators under Annex V. Neither the IMO nor the U.S. Environmental Protection Agency have set effluent or emission standards for the ashes, residues, or stack gases. The American Society for Testing and Materials (ASTM) Committee D-34 Waste Disposal is the proper group to develop performance and effluent standards, but there is no activity in D-34 to develop standards for incinerators of any size. The last attempt to develop such a standard failed due to a lack of agreement on what was acceptable.

In the United States, the operation of incinerators of a size suitable for shipboard use is not regulated by the Federal Government. At the state and port level, the regulation of small incinerators in communities ashore varies greatly. A shipboard incinerator might be subject to local incinerator restrictions if the incinerator is used while the ship is in port, just as ships operating in some California ports have to burn different fuels in order to meet the local air quality restrictions.

There are no IMO, United States, or Coast Guard residence time or minimum temperature standards for the combustion chamber used in shipboard incinerators. The Waste Combustion Equipment Council is working on an "industry standard" for incinerator performance. The classification society Germanischer Lloyd has developed regulations (Germanischer Lloyd 1987) and the Norwegian ship classification society Det Norske Veritas also has regulations for the equipment Det Norske Veritas (1980). In the United States, a shipboard incinerator construction standard and a selection guide are being developed under ASTM Committee F-25 Shipbuilding. When that is completed and accepted by ASTM, the Coast Guard may accept it as a technical standard. Until then, the Coast Guard is constrained to regulate incinerators according to its existing marine engineering regulations on auxiliary boilers: control systems, flameout protections, space ventilation, enough room around the installation, and fire protection.

I am skeptical about using garbage incinerators for destroying shipboard plastics. The Canadian experience with municipal incinerators seems to have fallen short of what incineration might promise, because operating the plants perfectly is so crucial to the environmental effectiveness of the technology (Mohr 1988). Shipboard incinerators, unless carefully tested and tended, may only make the plastics prohibition another shell game by dumping dangerous substances into the sea via the air and the ash.

Integrated Waste Collection, Treatment, and Disposal

Some firms have developed totally integrated ship waste handling systems, and these have been installed on a number of passenger vessels. Successfully operating these systems requires that the crew learn how the system operates and uses the parts of the system to their best advantage. Unfortunately, some have proved too easy to ruin when silverware is thrown into the incinerator or the shredder is fed a full dose of bed linens.

EXAMPLES FROM THE FLEET

How have ship operators actually responded? Many organizations are still trying to make cost-effective decisions about how to comply with the new Annex V requirements. Some examples can be given, but the identities of the fleets have been removed because this information is largely anecdotal and companies may still decide to change their approach as they develop permanent compliance. The compliance approaches presented are eliminating shipboard plastics, installing compactors, installing fuel-fired incinerators for select waste streams, and installing an incinerator for all shipboard wastes.

Eliminating Plastics

Company A operates chemical carriers in the domestic trade of the United States. Most of the voyages are between refineries in the Gulf of Mexico and tank farms along the eastern seaboard. A separate portion of the fleet services the west coast of the United States. The crews make short voyages with frequent port stops, but no foreign trips. For this firm, APHIS restrictions pose no problem. However, because the Gulf of Mexico is part of a trade route, the company has to think now about what might be needed to comply with a special area designation in the Gulf of Mexico. Company A began changing its supply procurement practices in 1987 to eliminate plastics and disposable goods wherever possible. Polystyrene coffee cups were banned and heavyweight paper cups were purchased instead. Crew support for eliminating plastics has been strong, because the trash problem in the Gulf of Mexico is apparent as they sail her waters. Further material substitutions will be made, such as asking suppliers to deliver maintenance supplies in metal cans rather than plastic containers. The company has no clear idea how much plastic waste they can eliminate from the ships' garbage, but they want to do as much as they can with replacing materials before locking themselves into an engineering solution. Equipment may be limited to galley comminuters and compactors, which fit more easily into the vessels' operations than do incinerators.

Compactors

Company B operates tankers with few people aboard along trade routes that bring the vessels into U.S. ports frequently. Company B chose to install compactors, after having previously considered installing incinerators on each vessel. The compactors are intended to be an interim compliance solution and Company B has not ruled out installing incinerators. First, however, the company wants to see what the wastes are on the ships, how they can be changed to nonplastic materials, and what standards for incinerator performance are developed by ASTM or IMO.

Incinerators for Selected Wastes

Company C ships carry general cargo and have a relatively small number of people working on board any vessel. They operate an irregular trade route around the Pacific with no guarantee of port facilities in some of the less frequently visited ports. Company C chose to install purpose-built diesel-fired incinerators to handle their waste while at sea and free them from relying on the uncertainties of the foreign port facilities. The managers and operators of the vessels appear satisfied with the units, which are regularly used.

Incinerator Installed for All Shipboard Wastes

Company D has tankers, so the ships have relatively few crew members, no passengers, and a steady load of maintenance activities with the probability of small oil leaks around machinery and deck piping fixtures. They service relatively remote terminals where it would be difficult to arrange for APHIS waste disposal. This firm elected to retrofit a large incinerator, so that the crew could destroy all the shipboard wastes without relying on port facilities for any garbage disposal. The experience of the fleet operators has been that the system works well so long as a high temperature is attained in the combustion chamber. One unanticipated limiting factor has been the disposal of dirty oil sorbent pads. The material of the pad itself burns nicely, but it also melts if the combustion chamber is not hot enough, and the melting pad material can pool and leak out the air inlets of the incinerator. The temperature of the chamber must be high enough when the pads enter the chamber to take the waste directly to combustion.

FUTURE MARPOL ANNEX V DEVELOPMENTS: SPECIAL AREAS

The term "special area" means an area where no dumping of garbage is allowed (U.S. Department of Transportation 1988a). An important point is that the requirements of each special area do not go into effect until all the national authorities bordering on the proposed special area officially notify the IMO that adequate reception facilities are available. Only then does IMO send out a global notice of the special area designation, and 1 year later the designation goes into effect. At this point, only the Baltic Sea has met that requirement. The Baltic Sea will be a special area as of October 1989. The North Sea has also been proposed and the border countries are filing notices with IMO. The formal designation of the North Sea as a special areas under Annex V will occur in the fall of 1989. The Gulf of Mexico, bordered by Mexico, the United States, and Cuba, has been suggested as a special area under the MARPOL Annex V (IMO 1988a). However, neither Cuba nor Mexico are signatories to the MARPOL convention and it is not possible for IMO to designate a special area without the advance consent of all nations surrounding the proposed area. The problems that face those who favor designating the Gulf of Mexico as a special area point up the limitations of MARPOL Annex V, even after its entry into force.

SUGGESTIONS FOR FUTURE DEVELOPMENT

Educating Passengers and Tourists

Passenger ships have been the source of a lot of garbage tossed into the sea (Smock 1988). Citizen outreach should include a campaign to tell potential passenger ship customers about MARPOL Annex V and their role in ensuring its success. Environmental professionals interested in eliminating marine debris should target the travel industry and the vacationing public with information emphasizing the benefits of the changes in shipboard handling of plastic materials. Passenger ship operators will be affected by this pollution prevention annex far more than they have been affected by any previous MARPOL annex. As "hotels" in a highly competitive travel and leisure market, passenger ship operators must have some assurance that complying with Annex V can be accomplished with a minimum of disruption to the carefree atmosphere that they try to provide to the vacationing passengers. Recent practice on many short cruises and "party boats" operating out of U.S. ports has been to use disposable materials, principally plastics, for many food and drink services. On longer voyages, passengers bring a variety of personal products for their own use. In North America at least, travellers can buy shampoos, razors, and deodorants in convenient unbreakable small plastic packages that are expected to be discarded when empty. Till now, there was no reason for a ship passenger to think twice about bringing aboard plastic containers. This may be the first time a person realizes the toothpaste tube is plastic. The MARPOL Annex V changes all that, and the travelling public should be encouraged via the travel magazines and other literature to learn to leave the plastic disposables ashore or to expect to keep them until returning to shore. The travelling public is increasingly sophisticated and will probably be glad to make such small changes, if it protects the pristine open sea that they desire.

Switching to nonplastic items will be a bigger adjustment on these vessels, because it will affect how service is delivered to the fare-paying passengers. First, fare-paying passengers cannot be compelled to sort their garbage, as crew members can, so the ship operator must devise a shipboard system that either handles all the collected waste without sorting, or depends on the crew members to separate the trash after it is picked up from throughout the ship. Second, replacing plastics in some instances will increase costs directly. For example, paper cups cost two or three times as much as expanded polystyrene cups cost. A passenger ship operator should be rewarded, not penalized, for moving away from the disposable plastics that are cheaper to use. Passengers and environmental organizations should praise the successful ship operators and challenge the others to do as well.

Develop Plastic Melters for Port Facilities or for Ships

This promising technology is already available for shoreside use, though it has not been widely used in the United States. The process reduces the volume of the typical plastic trash by a factor of 40, creating extruded blocks of plastic that are also likely to meet the hygiene and vermin-killing standards of the APHIS and PHS for shipboard sanitation. Plastic treated by a "melter" does not have to be sorted by material types. On the other hand, the plastic handled this way is not being recycled as such; it is simply being reduced in volume and must still be returned to shore for disposal.

Burning plastics may not be necessary, if a manageable melter for plastic wastes can be devised. A small unit might be useful for a passenger vessel or a small terminal, and a larger unit might be very useful for a remotely located terminal that has no easy way to handle the plastic wastes that are delivered by ships. The U.S. Navy is researching the development of a shipboard piece of equipment for use aboard its larger vessels, but that work is not expected to produce a prototype for several years.

Repackage With Selective Plastics

All plastics are not equal (Society of the Plastics Industry 1988). Incineration creates different combustion products, for example. Polyvinyl chloride polymer contains chlorine atoms, so that incinerating these materials is guaranteed to release hydrochloric acid. Other plastics, such as polyethylene or polypropylene, burn with less hazardous combustion products. In addition, plastics melt at different temperatures and react differently in waste treatment processes. So, the operators may gain some advantage in waste handling by changing from one kind of plastic to another. By investigating the types of plastic used in the products brought aboard ship, the ship operator can retain the advantages of using plastic in some products, but the disposal problems can be simplified, both at the ship and in the ports (Council on Plastics and Packaging in the Environment 1988).

In some senses, repackaging means rethinking away from disposable items to items that have a longer life span. Some shoreside restaurants have replaced plastic plates with plastic or wicker baskets that are lined with paper napkins for each serving. Yes, more paper napkins get used, but the waste bin has much less plastic debris in it.

Switch to Degradable Plastic

Some new plastic resins are being marketed as degradable, either because they photodegrade in ambient light or because they biodegrade when microbes decompose certain starches or celluloses used in their manufacture. These resins and any products made from them are considered plastic under Annex V and the Coast Guard regulations.

Refining Waste Handling to Large-Scale System

Now the APHIS system is set up to handle daily operations at airports, but it is much less prepared to handle daily operations at seaports. The APHIS organization must make the transition to be able to handle a larger volume of wastes, without the extraordinary arrangements that ship operators are having to deal with today. That may require more APHIS inspectors and will certainly require more APHIS-certified facilities accessible to arriving ships throughout the country.

Long-Range Prospects--Ten Years Down the Road

Ten years from 31 December 1988 should find the MARPOL 73/78 Annex V (Garbage) transition complete. At some time between now and then, ports and ships will learn how to manage shipboard garbage in a way that satisfies the annex, safeguards the sanitation and hygiene of the ship, safeguards the port country from animal or plant pestilence, and compensates the disposal firms without bankrupting the ship operators. After all, the shift in shipboard garbage disposal is not happening in isolation. Concurrently, shoreside communities and industries are recognizing that the present disposal practices for municipal garbage must change and that the popular use of "disposable" products leaves a permanent legacy ashore, just as it does at sea. The changes that the annex demands of the ship operators may soon be mirrored ashore. As more people confront the same garbage handling problems in their businesses and homes, engineers and designers will have more incentive to develop efficient products and processes, which may then offer a better alternative to the ship operators than those that exist now. Ten years from now, taking out the garbage will be very different, whether you are at sea or on land.

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LOW TECHNOLOGY (BURN BARREL) DISPOSAL OF SHIPBOARD-GENERATED (MARPOL V) WASTES

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ABSTRACT

To help ensure more widespread compliance with marine disposal laws, alternatives are needed that are applicable to a variety of wastes, but are less costly than using marine incinerators. Burn barrels are low technology burners for disposing of MARPOL wastes at sea. They are not considered state-of-the-art combustion devices, but they are a practical, technically feasible alternative. They comply with existing environmental and marine regulations and are currently in use. Design and operational guidelines for optimizing safety and combustion in burn barrels were developed.

INTRODUCTION AND REGULATORY FRAMEWORK

Traditionally, shipboard waste has been dumped at sea without regard for the impact of the waste on marine life or navigation. Marine debris is recognized as a growing problem, threatening marine life, beaches, and vessel safety worldwide. Public Law 100-220, The Marine Plastic Research and Control Act (effective 30 December 1988) domestically implements MARPOL Annex V. It restricts at-sea discharge of garbage to certain zones and bans all at-sea disposal of plastics. In addition, it requires ports to have available suitable waste reception facilities.

Shoreside disposal of certain wastes is resticted by U.S. Department of Agriculture (USDA) regulations for controlling plant and animal diseases and pests. Wastes contaminated by food from foreign ports (except Canada) must be enclosed in leakproof containers and brought ashore under USDA supervision. These wastes must then be disposed of via incineration, steam sterilization, or grinding into a sewer. Thus, existing regulations make disposal of shipboard wastes more difficult both at sea and ashore.

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

ALTERNATIVES FOR DISPOSAL OF SHIPBOARD WASTES

Under MARPOL and USDA regulations, vessel operators are faced with the following disposal alternatives, each of which has drawbacks:

- Incineration. True marine incinerators, those with combustion air fans, are expensive, moderately complicated, and occupy valuable deck space.

- Grinding. This process is generally suitable only for food wastes and cannot be used to dispose of plastics at sea.

- Compaction. Requires wastes to be stored, using valuable space. It creates possible odor problems and a potential for morale and aesthetics problems as the crew must work in close proximity to stored garbage.

- Onshore disposal (per local solid waste or USDA regulations). Drawbacks are similar to compaction, but uncompacted garbage requires even more space aboard ship.

- Biodegradable plastics. This may apply to some packaging materials; biodegradable rope and nets are not yet available; degradation products may be toxic or otherwise harmful to marine life.

- Burn barrels (low-technology burners). These may produce excessive harmful emissions or pose safety and fire hazards.

BURN BARRELS--ONE POSSIBLE SOLUTION

No single technology or disposal method can solve the marine debris problem by itself. A variety of technologies are necessary to accommodate the range of wastes produced, vessel and crew sizes, trip durations, and missions. To help ensure more widespread compliance with marine disposal laws, alternatives are needed that are applicable to a variety of wastes, but are less costly than using marine incinerators.

It has been reported that a variety of vessels are currently utilizing low-technology burn barrels to dispose of their wastes at sea. Burn barrels are simple (typically, a 208.2-L (55-gal) drum with some holes cut in the sides), "low tech," and similar to those barrels commonly used to burn household trash during the 1950's. The Marine Entanglement Program, National Marine Fisheries Service, NOAA, retained SCS Engineers to evaluate the technical feasibility, safety, and potential environmental impacts of using burn barrels to dispose of shipboard wastes.

It should be stressed that the burn barrel technique is not being advocated. However, under present regulatory authority, such technology is permissible and actively being utilized. Thus, the goal of the investigation was to provide guidelines for burn barrels that would enable legal disposal of shipboard wastes while protecting the environment, shipboard personnel, and the vessel itself.

Design Guidelines

Because actual construction and testing of a burn barrel were beyond the scope of this project, guidelines for the design, construction, and operation of burn barrels were developed (Fig. 1). A primary consideration was to optimize combustion, that is, to make the barrel act like an incinerator as far as practical in a unit with no moving parts. Types of wastes to be burned, environmental regulations, operator safety, and fire prevention were also evaluated. The burn barrel should be large enough to burn the expected volume of waste in a reasonable time, but without occupying too much deck space.

As shown in the schematic, a complete burn barrel installation should have the following features:

- Combustion chamber (208.2-L (55-gal), 16-gauge steel, Department of Transportation standard 17C drum) located inside an 321.7 L (85-gal) steel overpack drum.
- Combustion air inlets for underfire and overfire air.
- Air gap to cool combustion chamber and preheat combustion air.
- Spark arrester, grate, ash scoop or pan, rain cap.
- Suitable anchoring and insulation.
- Adequate clearances from all combustible surfaces.
- Location: aft and downwind.
- Nearby fire hose or extinguisher and first-aid kit.

Operational Guidelines

Operational guidelines for burn barrels are largely a matter of common sense. Primary concerns are good combustion and fire safety.

- Burn during calm sea conditions, avoiding rainy weather.
- Build the fire with loosely stacked paper and wood kindling, not with flammable liquids. Add plastics in small amounts to ensure burning rather than melting.
- Avoid potential explosives such as liquid-filled bottles and aerosal cans.

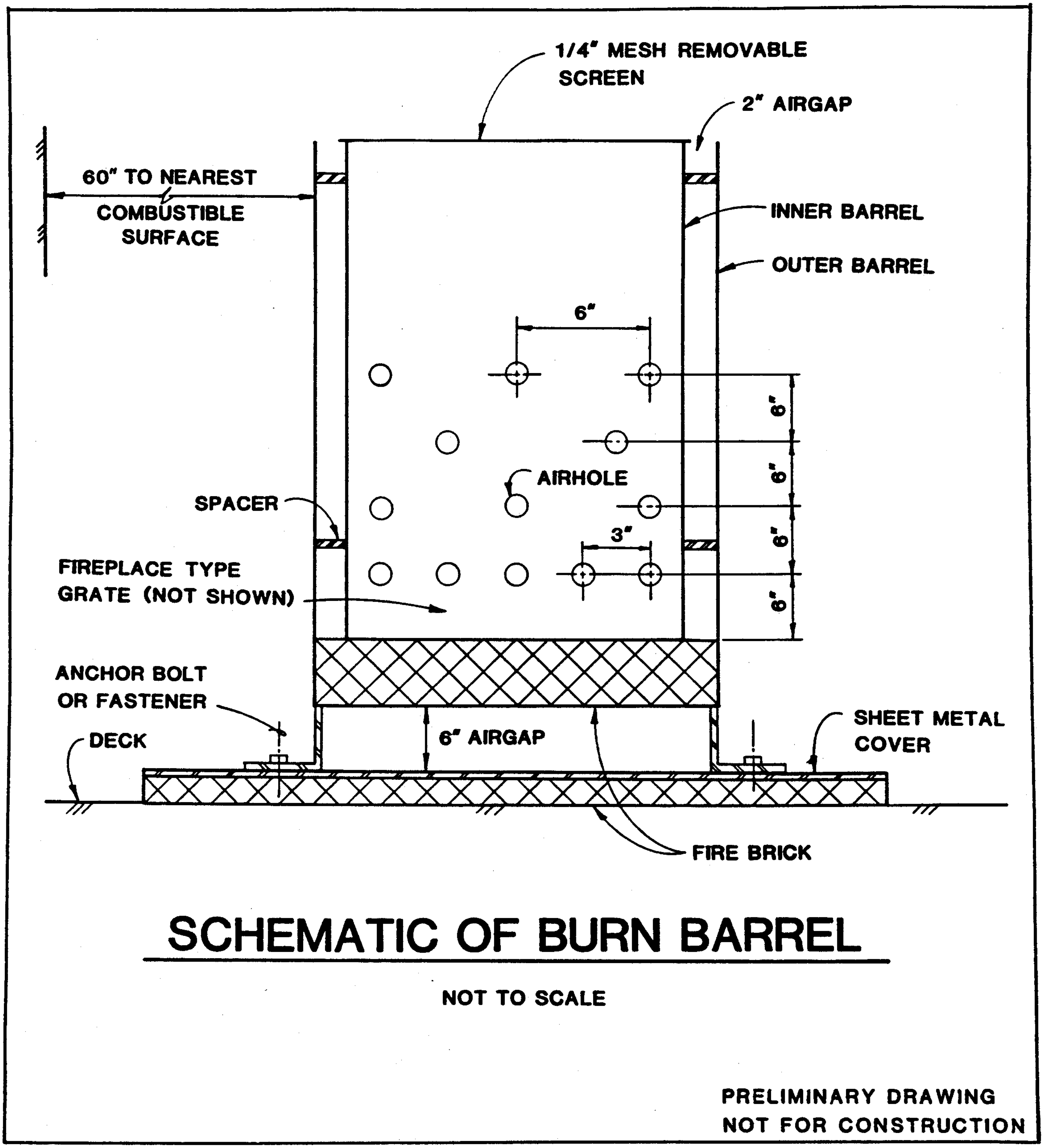

Figure 1.--Schematic of a burn barrel.

- Agitate the wastes with a metal poker for more complete combustion.

- Don't cook food over the fire.

- Wear safety goggles or glasses while operating the burn barrel.

- Avoid inhaling burn barrel smoke and fumes, which might contain hydrochloric acid from burning plastics.

ENVIRONMENTAL CONSIDERATIONS

Ash Disposal

The ash resulting from proper burn barrel operations should consist of only sand, dirt, metal, and glass (all of which do not burn); small amounts of unburned carbon (similar to charcoal); and small globules of melted plastic. The latter are still considered to be plastic and cannot be legally disposed of at sea. Since separating the plastic is inconvenient, the entire supply of ash should be stored in a metal container and disposed of properly ashore.

Air Emissions

The U.S. Environmental Protection Agency currently has no air pollution regulations that apply to burn barrels, and has no plans to promulgate any. State and local air pollution district regulations vary widely, and some of these may affect the use of burn barrels in certain coastal jurisdictions.

Actual air emissions from a burn barrel were not tested, but major components are expected to be water vapor, carbon dioxide, particulates (smoke), carbon monoxide, small amounts of hydrogen chloride (from chlorinated plastics and salt air), and various products of incomplete combusions.

The combustion conditions in burn barrels are more similar to open burning than to an incinerator. Furthermore, they lack air pollution control equipment to clean emissions. On the other hand, due to the small quantities of wastes per burn barrel, airborne emissions are expected to be modest. Air quality impacts from burn barrels operated on the open ocean are not anticipated to be significant. However, emissions testing of burn barrels is warranted.

COST CONSIDERATIONS

A burn barrel is expected to cost approximately $500, while steam sterilization of wastes to meet USDA regulations is estimated to cost about 30¢/lb. Assuming a 5-day trip with a 30-person crew generating 1.64 kg (4.4 lb) per person per day, it would cost about $200 to dispose of their wastes via steam sterilization. If a burn barrel were used instead, it would pay for itself in only 2.5 trips. Alternatively, a marine incinerator would cost upwards of $20,000.

CONCLUSION

While they are not considered to be state-of-the-art combustion devices, burn barrels are a practical and technically feasible alternative. When properly used, they appear to comply with existing environmental and marine regulations. It is believed that they can provide a safe, convenient, and low-cost alternative to either onshore disposal or incineration of shipboard-generated wastes.

PROVIDING REFUSE RECEPTION FACILITIES AND MORE: THE PORT'S ROLE IN THE MARINE DEBRIS SOLUTION

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ABSTRACT

A marine debris pilot project was conducted by the Port of Newport, Oregon, in response to the requirements of MARPOL Annex V. Project findings are summarized. The authors also document what has been learned from the preliminary application of these findings to several other west coast U.S. ports. They discuss the different aspects of refuse collection and recycling that should be examined by a port when gearing up for adequate dockside refuse disposal.

The technical part of dealing with marine refuse in a west coast U.S. port is seldom difficult. Initiating action can be--many ports and mariner groups do not consider marine debris a high priority item. However, those with port responsibility have responded positively to outside encouragement and minimal assistance.

INTRODUCTION

If mariners are expected to return plastics and other refuse to port they must have convenient dockside refuse disposal available to them. The U.S. Coast Guard has acknowledged this when writing the regulations to implement the provisions of MARPOL Annex V. Regulations require that all commercial ports and docks, no matter their size, provide refuse reception facilities.

While it may seem logical to expect all docks to have garbage containers, similar laws designed to control ocean pollution (e.g., those regulating oil or sewage disposal) have not succeeded because they failed to assure that facilities were universally available. Pollution containment facilities were required only of ports meeting some minimum size requirements. Mariners have often been uncertain where oil or sewage could be off-loaded.

Fortunately, this will not be the case with garbage. A fisherman off-loading fish at the processing house will be also able to off-load a

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sack of plastics or a used net. A fisherman from California, calling for the first time at a port in Alaska, will know that he can find a place to deposit trash and that the port must accept his old cable.

With these regulations then, ports and docks have been handed a much-expanded if not new role as garbage collectors--a role that many ports are unprepared to handle. Realizing this lack of preparedness and the crucial role that ports would play in solving the marine debris problem, the Marine Entanglement Research Program, of the National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA) provided funding for a pilot port project. Between January 1987 and May 1988, the Port of Newport, Newport, Oregon, conducted a demonstration program which addressed questions about port refuse disposal facility needs especially for fishermen and boaters, costs and cost recovery, and mariner education. A report, a detailed reference guide, and a videotape summary resulted from that pilot program and are available through the Marine Debris Information Offices, NOAA.

Work was begun in November 1988 to apply the findings of the demonstration project to ports and fishing groups on the west coast of the United States. It continued through June 1990. This work was coordinated by the Pacific States Marine Fisheries Commission with funding from a Saltonstall-Kennedy fisheries development grant. Various methods were used: Ports and fishing groups were sent written information and educational resources, marine debris exhibits were featured at trade expositions, and workshops and seminars were conducted with port groups, extension agents, and educators. Additionally, eight target ports (two in each of the west coast states) were visited periodically to provide them with direct assistance in assessing their refuse disposal needs and options, enlisting local mariner support, and encouraging community awareness. Targeted areas were chosen with the help of the commercial fishing industry and the Sea Grant marine agents. They were areas with active commercial and recreational fishing activity where need was shown and mariner and port support was considered likely. These port areas will in turn serve as examples for and be able to assist surrounding areas on the basis of their experiences. The target port areas were Petersburg and Homer, Alaska; Anacortes and Westport, Washington; Astoria and Coos Bay, Oregon; and Eureka and Morro Bay, California.

This paper will summarize the findings of the pilot port program. It will then mention what has been learned in applying the pilot project experiences to other port areas on the west coast of the United States.

PILOT PORT PROJECT SERVES AS MODEL

While no port is likely to be thrilled with the news that it is legally obligated to accept refuse from vessels, pilot project experiences indicated that ports can benefit by examining and improving their refuse handling system and by becoming involved in educating their customers about the marine debris problem. Some of the positive results of the Port of Newport pilot project were:

- a high and voluntary (Annex V had not yet been implemented) return of refuse back to shore;

- reduced port refuse disposal costs, despite the much-increased volume of refuse being returned;

- an improved rapport of the port with the fishing community;

- the pride of ownership mariners, port workers, and community members felt in the project; and

- frequent, positive media attention focused on the port and fishermen's efforts.

The acceptance and continuity of the marine refuse disposal project at the port resulted from:

- the convenience and comprehensiveness of the refuse reception facilities;

- the use of a simple, low-cost recycling system which reduced refuse disposal costs and port labor involvement;

- port management and worker support for recycling efforts; and

- fishermen's cooperation with port refuse and recycling efforts.

The support of commercial fishermen and other mariners for ocean cleanup efforts and for increasing community awareness of the marine debris problem resulted from:

- involvement of respected mariners and community members in the project advisory group and their willingness to take an active role in promoting awareness among their peers;

- direct contact with mariners, port workers, and community members (such as is achieved by conducting an oral survey, asking for ideas about improving the refuse system, or by organizing a beach cleanup) as a means of provoking thought and creating a sense of involvement;

- the widespread dispersal of a variety of educational and promotional materials such as brochures, decals, posters, displays, and slide and videotaped shows; and

- frequent local media reports of port, mariner, and community efforts to deal with the marine debris problem.

In work with other ports these approaches are emphasized and have been found to be generally adaptable.

APPLICATION OF PILOT PROJECT FINDINGS TO OTHER PORTS

The pilot port project differed from the situation to be encountered in most ports. The pilot project provided both focus and funds for marine debris work at the Port of Newport, minimizing port risk and financial restrictions and allowing the hiring of a full time manager, who was able to concentrate solely on marine debris work and plan and implement activities related both to facility development and education.

Though Annex V implementation might focus port attention on refuse facility work, ports we have seen seem generally unconcerned about this regulation's enforcement and have not made compliance a high priority. Most have not planned or budgeted for refuse system changes, nor assigned anyone to be in charge of carrying out necessary work. An active role in mariner and public education has not been considered by most ports.

What then of the Newport experience can be applied to other ports? Can the factors that made Newport's project successful--the convenient and cost-effective refuse disposal system which emphasized recycling, the mariner cooperation and support, and the community involvement--be counted on in other areas? What changes have been observed in work with ports that differ in physical size and layout, types of vessels and clientele served, type of equipment and services offered, and political organization?

Beginning Work With a Port

Given the general willingness of a port to look at its refuse handling situation in light of Annex V, the approach of holding a meeting to bring together the port, mariners, and refuse handlers has been found to be applicable and effective. Though it is unlikely that such a meeting will be initiated by either the port or the mariner group, we have found it easy to arrange by initiating the idea with these parties and asking the Sea Grant marine agents (or other community organizers) for help in identifying and inviting participants, arranging meeting facilities, and helping to moderate the discussion. The preliminary meeting is used to inform participants of the marine debris problem and the applicable laws, encourage the discussion of refuse service needs and options, and plan the necessary improvements.

In order to encourage the port to commit to making changes, it is important that mariner concern about the issue be evidenced by attendance at the meeting and participation in discussions. Mariner input to the port can be obtained at the meeting if the moderator will ask specific questions to draw out mariner discussion. It may be important for the moderator to discuss needs, ideas, and problems with mariners beforehand in order to foster honest discussion. The advisory group, if one can be formed, or an interested mariner group will need to follow through and continue to encourage the port to accomplish the suggested changes. While we have found that fostering the formation of an active advisory board is difficult unless a specific marine debris or solid waste project is defined, it is not an impossibility if a local person takes the initiative to keep things going, define a role for the advisory group, and call the meetings.

It is also effective for the moderator or a port official to ask about resources or specific commitments from the refuse haulers or recyclers at this preliminary meeting. (For example, What size bins can you provide? How frequently will the containers be emptied?) However, even with these details worked out, it is imperative that someone at the port be assigned to follow through to make the necessary arrangements.

In ports where either the port or the refuse service is operated under the jurisdiction of the municipality or city, special attention needs to be paid to informing these entities of mariner needs. City managers, engineers, and public works employees should be involved in the preliminary meetings with mariners and port officials in order to avoid subsequent problems and misunderstandings.

Gaining Port Interest

The attitude and interest of the port or dock manager or harbormaster regarding the marine debris problem and the new law will be the key determinants of progress regarding port refuse facility needs.

Many ports consider themselves to be already providing adequate refuse reception facilities, even though dumpsters may regularly overflow or be inaccessible, and mariners have no place to dispose of large refuse items. These ports need to be "pushed." That push can come from a manager who becomes especially interested in this marine debris issue. It is not uncommon to find such people, especially when the potential for more efficient refuse service and improved port-customer relations become apparent. Interested managers have quickly influenced change by establishing informal refuse reception areas (i.e., by beginning piles for wood, metal, and net), by speaking to mariners about new laws and port plans, by increasing the size of refuse containers, by pursuing recycling options, by including plans for marine debris facility improvements in their grant applications, and by encouraging education about marine debris in public schools.

We have found port and harbormaster groups quite interested in having their members informed of the new laws, refuse handling options, and available resources, and have found them quite willing to distribute written information and promotional materials to their members and arrange for presentations before their groups. We have also found harbormasters involved in marine debris work willing to share their experiences with their peers at port association meetings. These short presentations are extremely influential and generate many "hands on"-type questions, result in new cost-saving ideas, and foster a positive attitude toward attempting refuse system changes.

The biggest stumbling blocks we have encountered are not technical or financial, but attitudinal and political: managers who care only to meet the letter of the law, or who are unconcerned with user relations; city and port tensions that restrict port autonomy and the ability and willingness of the port to make financial commitments or changes or to solve problems (e.g., lack of cooperation between city and port in prosecuting the non-mariner citizens who use port dumpsters).

Assessing a Refuse System for Adequacy and Convenience

Analysis of the existing refuse handling system and port layout is useful in identifying problem areas and needs specific to that port's situation. It is important to critically examine refuse can or dumpster placement (for convenience and visibility), refuse container capacity, and emptying schedules to identify their adequacy in serving mariners and in handling refuse loads especially during the high-use times. The availability of carts, hoists, and forklifts for moving refuse may also be a determinant of convenience.

A one-time walk-around assessment is not adequate, however. Observations must be made during the various busy seasons of the port and these observations should be "reality checked." Resident mariners and port workers can be valuable resources for determining problem areas and times, but only if specific questions are asked. "When do refuse containers overflow and where?" gives much better information than asking, "Is the refuse system adequate?" It is also important to observe what mariners or the port actually do, despite what one might be told. For example, if a refuse container is located far from the access ramps to the vessels, notice whether the mariners actually use it, even if the port or mariners themselves report that they do.

Negotiating Refuse System Options

Often better service, additional service, and lower costs can be negotiated in port meetings with refuse haulers. In Astoria, Oregon, the port meeting with refuse company officials resulted in the willingness of the refuse hauler to back farther out on the dock to service a container. The Petersburg, Alaska, harbor district, under city jurisdiction, is meeting with city officials, who also operate the refuse service, to negotiate charges to account for the dumping of household refuse in port containers and for emptying half-filed dumpsters.

Determining Whether Recycling Will Work

A recycling system is a viable and cost-saving option for ports in which the following conditions exist:

- Ports are convinced that there are substantial benefits to recycling: recycling saves them significant refuse disposal costs, expands their refuse reception capacity, or provides a welcome service to mariners.

- There are operating recycling systems in the area and nearby markets for recycled goods. (If markets are far away, recycling is still a possibility if nonprofit groups can arrange with shipping companies to waive their backhauling charges.)

- Recyclers or community organizations will come to the port to haul away the collected materials without port involvement.

(Ports generally have shown little interest in collecting recyclables if they must also haul them away.)

- Port concerns about recycling can be addressed. Lack of familiarity with recycling, concern about system efficiency, and uncertainty about recycling markets are deterrents to port recycling interest. Ports need to be assured that the materials they accumulate will not be difficult to get rid of. Ports need to be willing to experiment with recycling.

- Recycling provides mariners increased convenience and benefit. Mariners will use recycling areas if they are provided at the point of disposal and if they are clearly signed. It helps if mariners are familiar with a recycling system or concept (e.g., fishermen in Coos Bay, Oregon, were aware of the Newport system; cardboard was already being recycled in the town of Bellingham, Washington).

Anticipating Recycling Potential and Possibilities

Refuse container contents can be examined and mariners queried to determine the types of waste materials generated and the potential for cost savings through recycling. Speaking to mariners will also indicate their level of awareness about recycling and their interest.

Visual examination of refuse container contents from port to port indicates that the amounts of metal, wood, paper, glass, and gear items found are quite variable. However, we have found that most all commercial fishing ports examined to date could realize cost savings by collecting and separating cardboard items for recycling. The recycling of this item is an easy and impressive first step and may stimulate further interest in recycling. (This was Newport's experience as well as that in Coos Bay, Oregon, where the harbormaster noted with much enthusiasm, "It works!")

In most ports serving the larger commercial fishing vessels, the establishment of a central area to both collect and store wood, cable, metal, and net items (for recycling or giving away) can provide a convenience to mariners and also encourage the proper disposal of particularly large items. Ports have often started these areas informally by stacking materials on pallets or in old containers, or by simply making distinct piles of different types of materials and posting signs. All those that have done so are impressed by how quickly additional materials get placed on the piles by mariners. Even hand-painted signs are effective in encouraging the proper sorting of refuse items. Ports that serve a primarily recreational vessel fleet will probably not find a need for such a central area, unless infrequent pickup of recyclable materials necessitates storage.

We have found that wherever there has been an established recycling program in a local area, it is relatively easy for the port to tie into it. Port contact with the recyclers has always resulted in their willingness to cooperate with the ports in establishing a workable recycling system and hauling schedule. Recycling containers need not be elaborate or expensive and can usually be built by the port or acquired. Refuse or recycling companies often provide free recycling bins, while donations of the bins can often be obtained from local businesses, from a city (e.g., they may have surplus bins), or from restaurants (208.2-L (55-gal) drums). School shop classes may also be willing to fabricate them. Ports may find it awkward to ask for such donations, and such requests may be easier and more effective if they come from a local mariner or a citizen.

Recycling containers must be able to be emptied easily by the recycler and must be clearly designated so as not to accumulate trash. Bright colors and clear signage are essential. The color blue is being used by most west coast ports for their recycling containers, with the idea that coast-wide consistency will make mariner recognition easier.

Seine and trawl nets are in demand by fishermen and the general public and will be removed from an accessible collection area if it is signed.

Though nets are made of materials with recycling potential (nylon, polyethylene, and polypropylene), used-net recycling efforts are still experimental in nature in the United States, and the details of collection, transportation, and market value of the nets are still undetermined.

At least 20 ports on the west coast have begun recycling programs. Table 1 summarizes these efforts.

Beginning a Port Recycling Program

Though ports may not set up a recycling system on their own, most welcome assistance in getting one started. The following steps are usually followed to establish a recycling program:

1. Assess refuse materials generated at the port.

2. Determine which materials are accepted or collected by area recyclers.

3. Explore demand and markets for uncollected but recyclable goods, e.g., fish nets.

4. Work with mariner groups and port to design a system that will be utilized.

5. Order or make recycling signs.

6. Order or make recycling bins or designate reception areas.

7. Implement the recycling plan, placing signs and bins.

8. Inform mariner groups of the bins and encourage their proper use. Inform the media.

Table 1.--West coast port recycling systems.[a] (Note: Used oil is also recycled at all these marinas.)

Port and contact	Type of materials collected	Collection methods	Other notes
Newport, OR Bud Shoemake (503) 265-7758	Cardboard, metal, wood Troll wire Metal, cable, wood, nets	Wood fish bins 208.2 L (55 gal) barrel Reception area, barge	System's 3d year Compounds/screens Refuse volume reduced one-third.
Charleston, OR Don Yost (503) 888-2548	Cardboard, metal, wood Cable, nets	Wood fish bins Reception area	8 h/month labor saves $200/month due to cardboard reduction alone.
Astoria, OR Bill Cook (503) 325-8279	Cardboard, metal, wood Cable, nets, some plastic	Reception area Reception area	New refuse area Completed December 1989.
Westport, WA Karl Wallin (206) 533-9528	Cardboard, plastic, lines Glass, cable, nets	Wood fish bins Wood fish bins	System in place October 1989 Located dockside and near office, launch ramp, net repair.
Anacortes, WA Dale Fowler (206) 293-0694	Metal, cable, nets, wood	Reception area	Got free advertising of net availability.
Bellingham, WA Art Choat (206) 676-2500	Aluminum, cardboard Wood, metal, nets	Wood fish bins Reception area	Recycling project assisted by Washington Sea Grant.
Friday Harbor, WA Bart Mathews (206) 378-3688	Glass (white, brown, green) Aluminum	Commercial 15.3 m^3 (20 yd^3) recycling bin, provided and hauled by garbage company	Recycling system so well-used had to enlarge and automate system.

Table 1.--Continued.

Port and contact	Type of materials collected	Collection methods	Other notes
Everett, WA Karen Bukis (206) 259-6001	Cardboard, aluminum, mixed paper, glass plastics (in 1991)	208.2-L (55-gal) barrels obtained from yogurt company for $8 each	Three barrels in each of 13 locations. Started April 1989, in first 10 months recycled 2,270 kg (5,000 lb) paper, 1,816 kg (4,000 lb) glass, 454 kg (1,000 lb) aluminum. Garbage bill reduced $7,500 from previous year.
Ilwaco, WA Bob Petersen (206) 642-3144	Aluminum cans Nets, cable, wood, metal	Wire mesh cans Reception area	Cans benefit baseball team.
Port Townsend, WA Andrea Fontenot (206) 385-2355	Cans, papers, glass	113.5-L (30-gal) garbage cans	Five roofed "environmental centers" built summer 1989. Part of waterfront revitalization plan.
Seattle, WA Marla Kleiven (206) 728-3394	Glass, aluminum, newspaper	208.2-L (55-gal) drums	In 11 cedar-fenced refuse areas at recreational marina.
Greg Money (206) 728-3395	All types recyclables, including plastics, paper	3.1 m^3 (4 yd^3) dumpster	Three locations at commercial fishing marina for comingled materials. Port pays to have hualed but less than for trash.
Sequim, WA Jan Hardin (206) 683-9898	Cardboard Glass, aluminum	Wood fish bins Wood fish bins	In place Planned for 1990.
Half Moon Bay, CA Bob McMahon (415) 726-5727	Cardboard, paper, glass Plastic jugs, aluminum	Rubbermaid 2-wheeled 208.2-L (55-gal) carts, transferred weekly to storage bins	Pilot study by Coastal Resources Center. Handbook available December 1990 from (916) 323-3508.

Table 1.--Continued.

Port and contact	Type of materials collected	Collection methods	Other notes
Oakland, CA area[b] Calvin Young (415) 891-3912	Aluminum, glass, plastic beverage bottles	Mini-house structures contain two 208.2-L (55-gal) barrels. PVC tube prevents removal of deposited materials	Materials for each of 27 units cost $200. Emptied twice/week even in winter. In operation since April 1989.
Kodiak, AK George McCorkle (907) 486-5438	Aluminum, plastics/rubber Wood, metal, nets/rope Paper/cardboard Batteries	3.1 m^3 (4-yd^3) dumpsters Separate collection area	Seven dumpsters in each of two MARPOL stations. Operating since February 1990.

[a]Other systems planned: Santa Cruz, CA, Steve Scheiblauer (408) 475-6161; Chula Vista, CA, Becky Clark, 550 Marina Parkway, Chula Vista, CA 92010; San Diego, CA area (a number of marinas); Libby Lucus (619) 235-0281; Edmonds, WA, Bill Stevens (206) 457-4505; Port Angeles, WA, Chuck Faires (206) 457-4505; Crescent City, CA, Rich Taylor (707) 464-6174.

[b]Six marinas.

9. Monitor the recycling system to make sure materials are hauled on time and problems are resolved.

The Port Role in Mariner and Community Education

Most ports will play a limited but important role in stimulating mariner awareness and involvement in the marine debris solution. Ports welcome and even solicit help from mariner groups, community groups, and recyclers to inform mariners of the refuse disposal law and to stimulate interest. The ports are willing to make notices about the law available to mariners and, when they are provided, will display posters and distribute stickers and brochures. A limited number of ports, fish processors, and dock facilities actively seek out information to pass on to mariners.

Ports may be willing to meet with their user groups to discuss Annex V regulations, but they are not likely to coordinate or organize such meetings on their own. Likewise, though most ports welcome press coverage about their marine debris efforts and do not object to public service announcements that say "brought to you by your local port," they are not likely to seek out media contacts.

A few interested harbormasters have actively sought support for marine debris cleanup efforts. The harbormaster in Petersburg, Alaska, spent a whole day going from boat to boat to explain the law to mariners and his need to raise moorage rates in anticipation of the extra refuse load. The harbormaster in Astoria, Oregon, showed marine debris promotional materials to a solid waste committee. He has asked for their assistance in contacting mariners on the docks and has inspired them to go into the schools to inform children. In Avila Beach, California, the port manager, a former teacher, is developing a marine debris educational package for school children.

Fishing Industry Support

Our experience shows that support from commercial fishing groups can be expected. Fishing industry groups are interested in solving the marine debris problem and are willing to become involved in marine debris work.

When supplied with information about Annex V, industry groups and Sea Grant marine agents will promote awareness of the issue through newsletters. They will discuss the regulations at fishing group meetings and encourage affirmative action among members. Industry groups have also been willing to promote marine debris awareness at expositions by handing out materials, displaying posters, talking with mariners, and by making display space available for marine debris pictures.

When prompted or during a meeting, fishermen as well as Sea Grant agents are willing to talk to their port harbormasters about refuse disposal needs and ideas. Many individual fishermen have personal interest in this issue, and their support is an essential factor influencing the attitudes of others, promoting peer action, and pushing for port changes. Some fishermen, when provided information and promotional items may also act on their own to bring this material to the attention of their peers, other mariner groups, and the schools.

Taking Action

Action related to the marine debris problem is unlikely unless someone takes charge. Someone must define and plan activities that address the marine debris problem, must organize and facilitate meetings, and must delegate the work. Do not assume that a port employee will take on or be assigned the lead role. If that level of involvement is not likely from the port, look for other individuals and groups for the port to work with.

Groups that have already been organized around beach cleanups or recycling are logical groups with which to work. They may be able to research or put together a port recycling program, coordinate a special promotional event, conduct mariner surveys, or organize a harbor cleanup or educational campaign. They are often willing to distribute information and show readymade video tape or slide presentations. The reference guide resulting from the Newport pilot project outlines such an outreach program, and emphasizes approaches such as involvement of port employees and mariners in program design and trouble shooting. This involvement has been effective in assuring the support of a marine debris program.

Groups already taking part in boater education efforts (e.g., the U.S. Power Squadrons and Coast Guard Auxiliary) can also provide support. They may be willing to incorporate marine debris information into their classes and during their contacts with mariners.

Other groups which may be interested in marine debris cleanup and recycling activities are environmental groups, community, senior, and scouting groups, and school science classes. They are most likely to act when they have readymade materials to give out or use. Interest and action are encouraged simply by making brochures, stickers, posters, curriculum materials, photo displays, and slide or video programs available to groups and teachers.

CONCLUSION

The technical part of dealing with marine refuse in a port is usually simple. Refuse containers are readily available in various sizes, hauling schedules or container sizes can be adjusted to meet increased demand, and recycling can often be used to decrease refuse disposal costs.

What is difficult is the initiation of action. What has been most apparent in work with the eight target ports, and with other ports on the west coast, is that while there is general support and interest by the port and mariner groups in the marine debris problem, it is not a high priority action item.

Most ports and mariner groups are not likely to take action on their own. However, if ports are approached, offered assistance, and encouraged (even by providing a simple catalyst such as information, notices, posters, or brochures) much can be accomplished. All ports have been willing to attend and even help organize meetings which bring them together with mariners, refuse haulers, and others. Once port officials are stimulated to begin (by the development of personal interest, by gaining the tangible assistance of supportive mariners or community groups, by guilt, or by seeing the examples set by other ports) we found that many then initiate activities on their own.

This essential outside push can be provided by a mariner, citizen, recycler, or community group willing to do some research regarding refuse and recycling options, organize meetings or activities, and encourage the awareness of mariners. States, counties, and cities may be able to designate part of an employee's time for such port assistance through their solid waste, environmental quality, boating, or fishing departments. If such a person can organize the readily available assistance of the fisheries groups and the ports, tangible progress on the marine debris problem will soon be noted.

Further information on the NMFS-sponsored pilot port marine debris project is available in two reports: "Report on a port-based project to reduce marine debris" and "Dealing with Annex V--reference guide for ports." The former report describes the project in detail. The latter presents guidelines and resources that resulted from the pilot project. A video tape about the Newport project called "A marine refuse disposal project" has also been completed. All three resources are available from NOAA's Marine Debris Information Office, 1725 DeSales Street, N.W., Suite 500, Washington, D.C., 20036, U.S.A., phone (202) 429-5609.

DISPOSITION AND RECYCLING OF PLASTIC PRODUCTS INCLUDING USED NETS

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ABSTRACT

Disposition and recycling technologies of various plastic wastes are reviewed. The technologies employed vary by material and type of waste.

Case studies were carried out at Akkeshi and Wakkanai ports in Hokkaido, which are major base ports of Japanese salmon fishing vessels. Some used nets are recycled into nylon pellets; others are incinerated or landfilled.

BACKGROUND

Recycling technologies in Japan have been developed because Japan is poor in some natural resources. Japan must import most raw materials needed to produce industrial goods, and there exists national recognition of the necessity to make the utmost of raw materials through recycling and other means.

Japan is also a small and densely populated country. It is not easy to find places for waste disposal, and the environment tends to be susceptible to damage from waste disposal practices. Thus, Japan finds it necessary to develop effective recycling technologies. To date, effective recycling technologies have been developed mostly by small- and medium-scale enterprises, rather than by public research institutes. Thus, these enterprises tend to be small in scale and of great variety.

There are two principal methods of recycling used fishing nets--pelletization and reutilization. Both methods have problems. Pelletization as a recycling business requires profit stabilization, while reutilization of nets requires further development of recycling methods in order to increase demand.

PLASTIC CONSUMPTION IN JAPAN

The output of primary products of plastics in Japan reached 4.77 million tons (MT) in 1987, an increase of about 12% over the 4-year period

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In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

from 1984. Responsible for this increased production is the continuous development of new plastic products, progressive development of synthetic technologies of resins, and the easy-to-process nature and low prices of plastics.

The lifespan of plastic products from marketing to disposal varies according to the resins and their products. The life of packaging materials and disposable containers, which together account for some 40% of plastic products, averages 1 to 2 years; on the other hand, sundry goods for household use and toys last for 3 to 5 years. As a result, 55% of plastic products are discarded within 5 years after their production. Pipes and other plastic products used in construction last for more than 10 years, but they account for only 20% of the total.

The most notable characteristics of plastic products are durability and low prices. The low prices, however, have brought about the "throw-away" practice; thus, the useful life of the products themselves is much shorter than that of plastic as a substance. The present problem is that the disposal of plastic is difficult, the difficulty stemming from its high durability.

CASE STUDIES OF RECYCLING WASTE PLASTICS

Introduced here are some Japanese technologies for recycling waste plastics. In recycling waste plastics, effective classification and separation of various plastics are essential to maintain good quality of recycled products and to lower production costs.

Plastic products are being used in almost every field, often in combination with wood, steel, or other materials. As a result, discarded plastics are mixed in with other waste material. Moreover, even if plastics are grouped by kinds at the time of refuse collection, they are usually covered with dust, earth, or sand, in which case additional processing is required.

Various techniques for classifying municipal refuse have been developed. They include techniques developed under the "Stardust '80 Project" conducted by the Agency of Industrial Science and Technology of the Ministry of International Trade and Industry in 1972-82 with the aim of turning such refuse into new resources.

There are two ways to recycle waste plastics--one is using it in new plastic products and the other is reducing the plastic as a material. Although in both cases quality control is a difficult task, this has developed into a new business in which 88 companies are already engaged throughout Japan. Recycled plastic products include manhole covers, piles, and flowerpots. The Ministry of International Trade and Industry has established the Japan Industrial Standard as guidelines for uses and quality control of such recycled products.

The pyrolytical method converts organic substances of high molecular weight into those of low molecular weight by use of heat energy. Suitable substances for this process are waste plastics, used tires, and waste oils. As opposed to incineration, pyrolysis needs not only strictly controlled operations, but must also meet two conditions:

- Waste plastics as materials must be even in quality and available steadily and in large quantity.
- A reliable supply system of recycled products like oil and gas must be established.

TECHNOLOGY FOR SORTING MUNICIPAL WASTES (STARDUST '80 PROJECT)

This system is designed to sort municipal refuse into two or three groups by applying both the pulverizing and sorting processes simultaneously. These processes utilize the principle that different materials can be crushed into different sizes in accordance with their resistance to shock, compression, and shearing stress.

One such group is composed of kitchen garbage, fragile paper, and other goods which can be easily reduced to small pieces and passed though small screen holes. Another group is made up of plastics, metals, fibers, stronger paper products (cardboard paper and laminated paper), and other things which cannot be broken easily and are extracted from the machine almost in their original sizes. When compared with conventional pulverizing machines, this system has the following advantages:

- Pulverization and sorting are possible in one process with a small amount of power.
- As metals, plastics, and other items can be selectively broken almost in their original forms, the system faces less wear and therefore entails lower maintenance costs.
- Owing to its slow speed, the device produces less noise, vibration, and dust.
- A special anticoiling device prevents long objects from wrapping around the rotating shaft.
- It is possible to easily discharge overloading objects such as metal blocks, bulk waste, etc., out of the system through adjustment of its rotating speed.

TECHNOLOGY FOR SORTING AGRICULTURAL FILM

This system is capable of sorting and utilizing soil-smeared agricultural films without resorting to a washing process.

Films are first roughly crushed (about 40 mm) and then sent to a heavy, oil-fired stirring dryer where the material is dried with 110°C hot air. Soil and sand are loosened from the films and discharged from the screen at the bottom of the drying chamber. Iron elements are eliminated by the use of magnets. The films are further crushed and once again dried (air drying) so that their quality is improved. After this, iron pieces are again removed by magnet and the films recovered in the form of fluff.

Recovery costs, excluding those of pelletization, amount to about ¥37.5/kg.

TECHNOLOGY FOR RECYCLING FOAMED STYROL FISH BOXES

Foamed styrol is used to make fish boxes and package cushioning, the latter used extensively in business offices and households.

Fish boxes are first used in fishing ports and later accumulated in markets and retail stores. Of the fish boxes handled in central wholesale markets throughout Japan in 1979, 42% were incinerated and about 22% were recycled.

Fish boxes to be recycled must be relatively clean. After being cut, they are heated and melted at 270°-280°C and molded into blocks weighing 8 kg each. These plastic blocks are exported through chemical companies to Southeast Asia, where they are used as raw materials for toys and re-exported to Japan, the United States, and elsewhere.

Such boxes were initially sold at ¥25/kg but their current price is ¥5/kg; the decline resulting from the price competition with virgin materials produced at low cost reflecting the current stagnant oil prices.

RECYCLING WASTE PLASTICS INTO ARTIFICIAL FISH REEFS

In Japan, the establishment of artificial habitats for fish has been promoted under a long-term national project designed to increase fish resources along the coasts.

Man-made waste plastics fish reefs are made of recycled polyethylene, polypropylene, and other polyolefin plastics derived from the plastic films used for packaging foods and other purposes.

In order to strengthen artificial fish reefs, various measures are taken, such as mixing ferro-oxide into the melted plastic to substantially increase density and building structural-use steel pipes into props. Between 1972 and 1988, a total of 250,000 m^3 of fish reefs weighing about 18,000 MT, were installed on the seabeds around the Japanese coasts. These artificial reefs have the following characteristics:

- There is no limit to their durability.
- As they are made of assembling units, it is easy to adjust their shapes and sizes.
- Easy to assemble, the time needed for installation is short.

- As they do not exude alkali elements, a variety of seaweed and shellfish can safely attach to the artificial reef.

TECHNOLOGY FOR RECYCLING FISHING BOATS OF FIBER-REINFORCED PLASTICS

About 1965, fiber-reinforced plastics (FRP) began to be used for building fishing boats. Easy to mold, lightweight, durable, and economical, FRP fishing boats have been used widely in the coastal fisheries. In Japan the number of powered FRP boats reached 290,000 in 1984. The earliest of these vessels have reached "retirement age," and safe disposal is now a major problem.

In 1985 and 1986, the Fisheries Agency developed an FRP boat disposal system. The disposal procedure is discussed below.

Chosen for the experiment was an FRP vessel from the set net fishery; the vessel weighed 3.42 MT and measured $9.86 \times 2.6 \times 0.59$ m. The vessel was first crushed by a hammer crusher into 10 to 20 cm^3 pieces. These pieces were carbonized in a batch-type pyrolysis incinerator which measured 3.4 cm^3. Waste tires were used as fuel for the carbonization process.

The plastics decomposed in the pyrolysis were gasified and recovered in the form of oils, which were further separated into water, tar, pitch, and waxes and stored as reprocessed oils. Glass fiber residue was burned in the pyrolysis furnace.

Recovered were the following substances:

- Oils--For reasons of smell, low calories, and irregular viscosity, the recovered oils were traded as products below C-class fuel oil (heavy oil).

- Glass fibers--Recovered glass fibers were utilized as composite plastics for compound plastics called AMC or FMC. Pending further research, they may be usable as molded products for automobiles. Their utilization as powdered glass may also be possible.

- Carbons--They are a mixture of products from FRP and waste tires. It is possible to market those sifted through an 80-mesh screen.

TECHNOLOGIES FOR RECYCLING AND INCINERATING USED FISHING NETS

Used fishing nets can be utilized in their original form for applications other than fishing or they can be reprocessed into basic material and used to produce other things.

Recycling of Used Fishing Nets in Their Original Forms

There is a wide range of purposes for used fishing nets other than fishing. These include:

Collection of Planktonic Larvae of Scallops

When used for catching planktonic larvae of scallops, one-sixth of a unit (about 100 m/unit) of nylon monofilament driftnet used in the salmon fishery is packed in one onion bag. Salmon driftnets are used and not squid driftnets; the latter are unsuitable because they are smeared with squid ink. Scallop fishermen buy used nets from net-weaving companies at a price of about ¥1,600 per unit (including shipping costs) in Hakodate, Hokkaido.

Protection of Trees From Deer

In 1986, in order to protect trees in the training plantation of Kyoto University in Shibecha, Hokkaido, a reforested area within the plantation was surrounded with nets 1.4 m high that had been used previously for salmon fishing. Before such protection, 79% of the 86 trees in the area had been damaged by deer, *Cervus nippon esoensis*. No further damage has been reported since the installation of the nets.

Although such protective nets can be considered effective for preventing deer from harming trees in Hokkaido, this method is costly and labor intensive. In Chiba Prefecture located east of Tokyo, a deer was reported to have died when its antlers became entangled in a net.

Drying Tangle

In Japan, tangle is usually dried on pebbles after it is gathered from the sea. In some regions, trawl nets are used instead as drying racks.

Antibird Nets at Garbage Collection Sites

In Wakkanai, Hokkaido, used trawl nets cut into 2-m squares are spread over garbage cans at community garbage collection sites so that crows cannot scatter the garbage.

Reprocessing of Used Fishing Nets

Since 1988, three factories (two in Akkeshi and one in Hakodate) have been in operation pelletizing used nylon monofilament salmon and squid driftnets. The companies collect nets from various ports in Hokkaido. The pelletizing process is similar at all the companies and total production is an estimated 700 MT a year. The pellets are sold to chemical companies at a price of about ¥210/kg (1988) for the manufacture of electrical equipment for automobiles, bicycle saddles, electric fans, and other kinds of goods. When compared to virgin pellets, however, the tensile strength of recycled pellets is reported to be weaker by 10%.

One of the problems concerning pelletization lies in the great effort required in washing nets or otherwise removing impurities from them. Trawl nets are more likely to retain soil and trash at their webbings due to the method of fishing. As far as we are informed, there is practically no reprocessing of trawl nets at this time, presumably due to the cost of preparation.

Economically, the competitive advantage of reprocessed pellets over virgin pellets is very unstable; the price of the latter being subject to the price of petroleum.

Incineration of Used Fishing Nets

In Japan, as a means of reducing the volume of bulky fishing nets, high heat incineration, which is effective in minimizing harmful substances and ash, has been under study. Under consideration are batch-type pyrolysis furnaces (0.7 to 50 m^3 in size) placed underground and designed to attain complete combustion through use of water-gas reactions.

This furnace is constructed so that combustion may take place using an air intake from above. This also makes it possible to adjust the supply of air so as to prevent unburned soot and dust from being discharged. The chimney flue helps combustion by serving as a secondary furnace.

When burned, plastics generally give off black smoke and, in some cases, harmful gases. No noxious smell or black smoke is produced, however, in this particular type of incinerator, even if used fishing nets, tires, foamed styrol, or lumps of plastics are burned.

RECYCLING OF USED FISHING NETS IN HOKKAIDO

Information regarding recycling of used fishing nets in Hokkaido was obtained from oral surveys conducted among staffs at government offices, fishing operators, net-weaving companies, and other related industries in Akkeshi and Wakkanai in 1988. Akkeshi is one of the five main ports in Hokkaido engaged in medium-sized salmon driftnet fishing operations. It is also known as a port for the squid driftnet fishery. Wakkanai, on the other hand, is a port mainly supporting a trawl fishery.

Akkeshi

Use of Fishing Nets

As of 1987, fishing operators in Akkeshi owned 13 fishing boats authorized for use in salmon and trout fishing with medium-sized driftnets. Six of them were also engaged in driftnet fishing for squid. In addition, 10 other boats from other ports landed their catch at Akkeshi; these vessels were not involved with the disposition of fishing nets.

Medium-sized salmon driftnets in use at Akkeshi mostly measure about 100 m in length. When the salmon and trout fishing season using medium-sized nets comes to an end around July, some nets are used again for squid catching and then scrapped. Nets aboard boats used exclusively for salmon and trout fishing are transported to net-weaving companies. About 50% of the nets need no repairs and are used again the following season; 30 to 40% of the remaining nets are repaired and used again. About 20% of the salmon and trout fishing nets are scrapped each year, and almost all nets used to catch both salmon and squid are scrapped after the cuttlefish season ends. The lifespan of nets averages from 2.5 to 3 years.

Disposal and Recycling of Fishing Nets

For lack of landfill space and to avoid pollution, Akkeshi Town does not incinerate used fishing nets or discard them in landfills, although it discards foamed plastics like fish boxes as "incombustible refuse." Fishing operators burn their ropes and buoys separately.

In Akkeshi, there are two companies that reprocess nylon monofilament salmon and squid driftnets into pellets. Used nets are either brought to the processors by fishing operators and net-weaving companies or gathered without charge at port collection sites. Nets purchased from net makers and repairmen cost the processors ¥20/kg. It is estimated that about 600 to 900 MT of used nets are collected within and from outside Akkeshi annually. Among them, those unfit for recycling are incinerated by the reprocessors. The rest are melted and pelletized into an estimated 450 MT at the two reprocessing companies. Before 1987, some used fishing nets were exported through trading firms to China and Taiwan to be made into valves and other products. Such exports are not carried out today because of the unfavorable prices of petroleum.

One of the two pellet processors in Akkeshi is capable of producing 1.5 MT a day in a 9-h operation, but such facilities are in operation for only about one-third of the year. The company spent ¥14 million on a washing machine and another ¥13.5 million on a machine for melting and pelletizing plastics, with the total investments estimated to be some ¥60 million, including the land and building. The monthly production of 15 MT of pellets requires ¥740,000, including ¥200,000 for fuel and electricity and ¥520,000 for 100 man-days of labor.

Wakkanai

Use of Fishing Nets

As of 1987, Wakkanai had 19 boats which were allowed to fish in the offshore trawl fishery. On an average there are about 10 fishing nets for each boat; usually 2 or 3 nets are loaded on the boats, and also on board are 1 or 2 nets to be repaired. The remainder of the net supply is stored in warehouses or other locations of the fishing operators or net-weaving companies.

Damaged nets are repaired aboard the fishing boats when the damage is slight. Major repairs are made either in the fishing operators' own net-weaving shops or shops of independent net-weaving companies. Repairs usually become necessary after six or seven fishing operations; repairs mostly concern the dislocation of rope from net mesh. Net webbing usually lasts for 2 years. Torn webbing is usually not mended, but replaced with a new section of webbing. Fishing operators spend about ¥10 million each year for net-repairing purposes.

Scrapping of Fishing Nets

Scraps of trawl webbing are accumulated during the process of repairing by net-weaving companies and fishing operators. About 15 to 18 MT of scrapped webbing is accumulated by net-weaving companies; the total excludes webbing used for heating purposes during winter. The amount of scrapped webbing accumulated by fishing operators is estimated at 17 MT per year.

Disposal and Recycling of Fishing Nets

Scrapped nets not used for heating or recycling are brought to garbage disposal plants in Wakkanai. An estimated 700 MT of fishing materials are brought to landfills annually, accounting for 1.6% of the municipal total in 1987. Of the 700 MT, nets made up 80% and ropes, 20%.

Some of the scrapped nets are incinerated at establishments of net makers and fishing operators. Here, stoves used as heaters during winter burn nets exclusively (or together with waste oil). This is probably the most popular method of used trawl net recycling practiced in Wakkanai.

Between 1982 and 1987, a producer of animal feed in Wakkanai used scrapped trawl nets as an auxiliary fuel in its coal boiler. To operate the boiler the company burned 30 used 12-MT truck tires every day and burned 2 to 3 MT of scrapped fishing nets every year. The feed producer obtained these nets free of change at net-repairing shops.

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